# APPLE ADULTERATION DETECTION AND QUALITY SORTING

By

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A Final Year Design Project (FYDP) submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of BSEEE

Electrical and Electronics Engineering
Brac University
May, 2025

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## Declaration

It is hereby declared that

1. The Final Year Design Project (FYDP) submitted is my/our own original work while completing degree at Brac University.
2. The Final Year Design Project (FYDP) does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The Final Year Design Project (FYDP) does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.

4. I/We have acknowledged all main sources of help.

**Student’s Full Name & Signature:**

| | |
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| **Prithwiraj Biswas**<br>21321044 | **Rubaiyeat Tanzir Isty**<br>21321043 |
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# Approval

The Final Year Design Project (FYDP) titled “Apple Adulteration Detection and Quality Sorting” submitted by

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of Spring, 2025 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of BSEEE on [Date-of-Defense].

**Examining Committee:**

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## Ethics Statement

Our project had a similarity report of 17% most of which were material such as the table of contents page, specifications, chapter headings. No AI has also been detected by turnitin.

# Abstract/ Executive Summary

In the pyramid of human necessities, food reigns high. Therefore, reliable adulteration detection and quality identification of any type of food not only keeps the fraudulent business practitioners in check but also ensures good quality food is being produced and consumed for one’s hard earned capital. Unlike disaster detection kits such as gas leakage or fire detection - here accuracy needs to be prioritized over speed as one’s long term health is concerned. In this project, we narrowed down our focus to just apples as it is the most consumed fruit in the world and we will be making our own dataset for improved accuracy and robustness. We have developed a medium sized portable box that can detect apple adulteration and quality - which, thanks to our inhouse dataset, can be expanded upon for industrial use.

**Keywords:** Adulteration Detection, Quality Identification, Image Processing, Machine Learning, Convolutional Neural Network (CNN), Raspberry Pi, Real-Time Detection.

## Acknowledgement

We would like to thank our ATC panel chair - Professor Dr. Mirza Rasheduzzaman sir for guiding us and pushing us with constructive criticism. We would also like to thank Md. Mehedi Hasan Shawon, Lecturer, Brac University for guiding us to follow different conventions. Finally, we would like to thank Tasfin Mahmud, Lecturer, Brac University who guided us a lot during our initial stage of this project.

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# Chapter 1: Introduction- [CO1, CO2, CO10]

## 1.1 Introduction

The pace with which technology has boomed in the past 100 years has been unprecedented. The rapid development is only limited by what we can imagine. We have given thought on how to make communication easier so that loved ones do not have to wait for months in order to get a reply to their letters or so that information can be relayed more quickly, so we invented satellite communications. The supercomputer that sent men to the moon for the first time does not even come close to the computing power that we have in the palm of our hands nowadays. We needed faster modes of travel so we invented the airplanes, a feat once only thought about in science fiction. This concludes that necessity is the mother of invention. We have given so much thought to everything we didn't have, that we overlooked the things we already had. This resulted in us taking things such as freshwater, clean air and healthy foods for granted.

In the context of our project, a comprehensive solution to bring safer and better food to someone's table does not exist at a notable scale. Food sustains us and provides us with the nutrients required to sustain life. Therefore, it is fundamental to focus on the development of an accurate and robust food grading system which can alleviate health issues associated with consuming low quality food. It can also elevate the agricultural sector of a country when producers realize that better quality food is in demand - which will require them to up their game ensuring that farmers also get fairer wages for their hard work.

### 1.1.1 Problem Statement

Food adulteration, otherwise known as "food fraud", is something that can be traced back to the 18th/19th century. Even though its roots can be found in Europe and North America - it is now more prevalent in developing or under-developed countries where corruption is rampant. Adulterated food frequently seems to give rise to various illnesses such as diabetes, diarrhea, nausea, cardiovascular disease, etc [2]. Amongst the different adulteration techniques, formalin adulteration is the most prevalent due to its antiseptic and preservation properties [1]. In a review of the damage done by adulteration of such type it has been found that formalin accumulates in the body following a period of long term consumption, leading to both acute and chronic conditions [1]. Acute conditions include abdominal pain, vomiting, coma, renal injury, and even death whereas chronic conditions include respiratory problems, eye, throat, and nose irritation, and a high chance of respiratory and brain cancer [1, 4]. This obviously makes it a health issue and the diseases caused by such adulterants end up putting strain on the health sector of a country [3], this also results in requiring to put more tax money on the health sector which a developing country like Bangladesh can better utilize elsewhere [3].

However, formalin adulteration is prevalent in countries like Bangladesh for a reason. Just last year, in 2023, Bangladesh was ranked 3rd largest food importer in the world - with an import of more than 12.5 million tons [5]. This is because farmers in this country are paid a meager wage [6]. This results in there being no incentive for the farmers to put time and effort behind the crops they are growing which equates to poorer quality of crops. As such our country has a growing demand for healthier, better quality produce from abroad. So if a system is put in place that will pay the farmers more based on the quality of their crops, we can get higher quality produce locally instead of relying on foreign imports to ensure consumer satisfaction and market value. Imported produce sees more adulteration in order to keep them looking prettier for longer period of time and so that they can be sold for more money to makeup for the cost of import [1]

### 1.1.2 Background Study

Adulteration comes in many forms. Since the traditional method of formalin detection is quite intrusive or requires chemical knowledge, an alternative is long overdue. Current method of formalin detection includes paper titration method, which even though gives prompt and FDA regulated response in 1-5mins using acid-base titration [1], is not something that can be carried out by an average person. Using various forms of colorimetry as the detection method poses similar problems [1]. If we decide to opt for a colorimetric sensor array with proper calibration, it will make it so that an average person can operate the formalin detection process - however, the detection time is approximately 75 minutes which is not optimal [1]. Image based detection of formalin is also not plausible as we cannot flag every perfect looking apple as one that has been tampered with. This type of image based detection is possible in cases where the visual signs can be distinguished by an algorithm such as using sawdust to adulterate spices or using grounded peanut shells to adulterate almond powder [7,8]. We found out that a simple formalin sensor works to streamline this process if calibrated for background noise, keeping it simple and yet accurate enough for in-house use.

Now, moving onto our sorting part where apples are categorized according to their freshness, we can see some advancements have been made. Effective methods for assessing the quality of fruits include bio-molecular sensing technology, hyperspectral and multispectral imaging techniques, as well as traditional machine vision technology. In [9], we see the use of bio-photonic technology to improve apple disease detection. We also see Zhang et al. using hyperspectral transmittance imaging with a full wavelength model to detect blueberry bruising [10]. An image recognition model was also used to inspect various damages, bruises and apple decay by multispectral imaging [11]. Bhargava and Bansal were observed developing a fruit grading system using Support Vector Machines (SVM) to classify single-colored apples into categories of healthy or defective, based on features like texture, shape, and statistical attributes [12]. However the problem with the above experiments is that they are only for the detection of diseases and do not carry out detailed classification. Recently, artificial intelligence techniques, particularly deep learning and convolutional neural networks (CNN), have made significant advances in detecting and classifying fruit quality. In [13], the researchers achieved a training accuracy and testing accuracy of 96.5% and 92% respectively after using a Deep Learning based CNN model to detect defective apples. Similar use of CNN can be seen in [14], where the researchers identified early peach decay with an accuracy of 97.6%. The above studies provide a nice framework for us to work and build upon and using our own dataset and a similar use of CNN we can create a robust apple classification system. Another prime reason for choosing CNN is because a standard convolutional neural network (CNN) is composed of an input layer, convolutional layers, fully connected layers, and an output layer. Unlike traditional artificial neural networks (ANN) where all neurons are interconnected, CNNs utilize local receptive fields and shared weights. This design significantly reduces the number of training parameters required.

### 1.1.3 Literature Gap

During our research we have found out that various methods for detecting formalin in fruits and quality sorting techniques exist, however, some notable gaps were identified in their application and effectiveness.

**Detection Method:** The current method of detection for formalin adulteration is either laboratory based or requires sophisticated equipment. Both of these methods also require trained personnels. There is a need for easy to use and cost effective on-site formalin detection

**Quality Sorting:** The ML system is expensive, limiting their use in small to medium scale operations.

**Integration of Detection and Sorting:** There is almost no research on systems that integrate both formalin detection and quality sorting into a single automated solution. Such integration could streamline the process, enhancing efficiency and ensuring that only high-quality, safe fruits reach the consumers.

### 1.1.4 Relevance to current and future Industry

Human health is something that has and always will stay pertinent. As such, our project is and will stay relevant considering both urban and industrial settings. From an urban context, this will allow people with little to no technical knowledge to check for inconsistencies in their food and when scaled to an industrial standard in the future it will allow for the problem to be driven out from the root source. For example, if the food is checked directly by the wholesale buyers using large scale versions of our prototype - it will work to not allow any adulterated food to reach the market. However, as we know, it is folly to put complete trust in a stranger. For all we know, the wholesale buyer themselves could be corrupt and be in on the dishonest practice. As such, the portable version will also always stay relevant.

Furthermore, there are a lot of places where quality sorting is done manually by labourers. So in a world that is rapidly heading towards full on automation, our product will work to automate the process completely negating the need for time consuming and tiring manual labour.

## 1.2 Objectives, Requirements, Specification and constant

### 1.2.1 Objectives

1. Create an integrated system capable of detecting formalin and sorting apples based on quality parameters, aimed at ensuring food safety and quality control.
2. Ensuring fair pay for the farmers for hard and honest work.
3. Contributing to overall food safety which will lead to better lifestyle for the consumers through better health obtained from eating unadulterated food.
4. To increase the quality of food in the long term when producers realise they are getting better pay for better quality of food.

### 1.2.2 Functional and Nonfunctional Requirements

**Functional Requirements:**

1. **Power source:** Power source is required to power up the whole system.

2. **Data Collection, Preprocessing and Storage:** Collection of diverse datasets of apples. Preprocessing is required so that the data can standardise features and handle missing values. The system must store captured and processed images locally on the Raspberry Pi's storage or upload them to a cloud storage service for analysis.

3. **User Interface:** The system should output results in a graphic interface of processed images and final classification to the users.

4. **Formalin Detection:** The formalin adulteration should be detected using formaldehyde sensors.

5. **Quality Sorting:** Image processing aids in categorising the quality of the fruit by giving it appropriate grades using another prediction mechanism.

**Non-Functional Requirements:**

1. **Exterior Design:** The system should be small, compact, lightweight and visually appealing as a final furnished electronic product.

2. **Accuracy and Reliability**: Adulteration of the fruit samples should be detected with high accuracy.

3. **Scalability**: The solution should be scalable enough to reach a usable amount of fruit samples that are handled for deployment.

4. **Reliability:** The system must reliably capture and process images without crashes or failures.

5. **Maintainability:** Easily accessible to software and hardware components to be maintainable and upgradable.

6. **Robustness**: The system should be robust against a wide range of light conditions, fruit samples and potential sensor noise (if any) in the process. At the same time, any anomalies should be addressed.

7. **Real-Time Operation:** One commonality amongst the models we use for detection is that they support real-time detection so low latency at inference time should be a must.

### 1.2.3 Specifications

**Table 1**: Specification for Design Approach 1

| Design Approach 1 | | |
|---|---|---|
| **Subsystem** | **Components** | **Specifications** |
| Power Systems | Rechargeable Lipo Battery 2200mAh 11.1V 2S | Brand Name: XW Power Eagle Lipo<br>Voltage: 7.4V<br>Capacity: 1500mAh<br>Cell Type: Lithium Polymer<br>Configurations: 2S<br>Continuous Discharge Rate: 25C<br>Max Burst Rate: 90 C<br>Discharge (Output) Lead: T plug connector<br>Charging(Balancing) Lead: JST-XHR<br>Wire Length: 100mm<br>Operating Temperature Range: -20 to 60 degrees<br>PVC color: Silver and Black<br>Shipment Weight : 0.078kg |
| | MP2315 Mini Adjustable DC-DC Step- | Ultra miniature size |

| | | |
|---|---|---|
| | Down Module | MP2315 converter IC<br>Adjustable output voltage / optional fixed voltage outputs<br>Excellent load and voltage regulation<br>Output current 1.5A with peaks up to 2A<br>Input voltage range 4.5 to 24V<br>Output voltage range 0.8 to 22V<br>Output enable pin compatible with 3.3 & 5V logic |
| Array of Sensors | CJMCU-1100 MS1100 (Formaldehyde/Formalin Detection Sensor) | Voltage : 5V<br>Working Current : 100mA(max)<br>Circuit Voltage : 12 V DC<br>Sensitivity : 3%<br>Response Time : 5s<br>Response Time : 10s<br>Working Temperature : 10-60 °C<br>Humidity : 90%<br>Shipment Weight : 0.012kg |
| Computer Vision | Webcam | Fixed focus lens on-board<br>Improved resolution - 8-Megapixel native resolution sensor- capable of 3280 x 2464 pixel static images<br>Supports 1080p30, 720p60 and 640x480p90 video<br>Weight just over 7g<br>Connects to the Raspberry Pi board USB<br>Camera v2 is supported in the latest version of Raspbian, |

| | | |
|---|---|---|
| | | Raspberry Pi's preferred operating system<br>Uses the Sony IMX219PQ image sensor - high-speed video imaging and high sensitivity |
| Microcontroller Unit with Communication Module Internet of things(IoT) | Raspberry Pi 4 Model B Board With 2GB LPDDR4 SDRAM (with acrylic case) | Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz<br>2GB LPDDR4-3200 SDRAM<br>2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE<br>2 USB 3.0 ports; 2 USB 2.0 ports.<br>2 × micro-HDMI ports (up to 4kp60 supported)<br>2-lane MIPI DSI display port,2-lane MIPI CSI camera port<br>4-pole stereo audio and composite video port<br>H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)<br>OpenGL ES 3.1, Vulkan 1.0<br>Micro-SD card slot for loading operating system and data storage<br>5V DC via USB-C connector (minimum 3A*)<br>5V DC via GPIO header (minimum 3A*)<br>Operating temperature: 0 – 50 degrees C ambient |
| Rotating Platform | Nema 17 stepper motor | 1.5A to 1.8A current per phase<br>1-4 volts<br>3 to 8 mH inductance per phase<br>44 N·cm (62oz·in, 4.5kg·cm) or more holding torque |

| | | |
|---|---|---|
| | | 1.8 or 0.9 degrees per step<br>(200/400 steps/rev respectively) |
| | IBT-2 Motor driver | 27V (B+)<br>Control motor speed by PWM up to 25 kHz.<br>Motor forward and backward motion control.<br>Switched mode current limitation for reduced power dissipation.<br>Current limitation level of 30 A Current sense capability.<br>Over-temperature shut down Over-voltage lock out.<br>Large size heat sink is mounted to driver.<br>Size: 451.2 cm.<br>Weight: 66 gm |
| User Interface Unit | 3.5 Inch Raspberry pi Display | LCD Type: TFT<br>LCD Interface: SPI<br>Touch Screen Type: Resistive<br>Touch Screen Controller: XPT2046<br>Colors: 65536<br>Backlight: LED<br>Resolution: 480*320 (Pixel)<br>Dimensions: 84.91x56.54 (MM)<br>Compatible with Raspberry Pi B, Raspberry Pi B+, Raspberry Pi 2 & Raspberry Pi 3 |

**Table 2**: Specification for Design Approach 2

| **Design Approach 2** | | |
|---|---|---|
| **Subsystem** | **Components** | **Specifications** |
| Spectroscopy Module | NIR Sensor (SparkFun AS7263) | Near-Infrared, Qwiic interface, digital spectral sensor |
| | UV-Vis Sensor (GY-ML8511) | UV Light detection module, analog output, 280–390nm UV range |
| Colour Detection | Colour Sensor (TCS3200) | UV Light detection module, analog output, 280–390nm UV range |
| Processing Unit | Raspberry Pi 4 Model B Board With 2GB LPDDR4 SDRAM (with acrylic case) | Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz<br>2GB LPDDR4-3200 SDRAM<br>2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE<br>2 USB 3.0 ports; 2 USB 2.0 ports.<br>2 × micro-HDMI ports (up to 4kp60 supported)<br>2-lane MIPI DSI display port,2-lane MIPI CSI camera port<br>4-pole stereo audio and composite video port<br>H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)<br>OpenGL ES 3.1, Vulkan 1.0<br>Micro-SD card slot for loading operating system and data storage<br>5V DC via USB-C connector (minimum 3A*)<br>5V DC via GPIO header (minimum 3A*)<br>Operating temperature: 0 – 50 degrees C ambient |

| | | |
|---|---|---|
| | | |
| Power Systems | Rechargeable Lipo Battery 2200mAh 11.1V 2S | Brand Name: XW Power Eagle Lipo<br>Voltage: 7.4V<br>Capacity: 1500mAh<br>Cell Type: Lithium Polymer<br>Configurations: 2S<br>Continuous Discharge Rate: 25C<br>Max Burst Rate: 90 C<br>Discharge (Output) Lead: T plug connector<br>Charging(Balancing) Lead: JST-XHR<br>Wire Length: 100mm<br>Operating Temperature Range: -20 to 60 degrees<br>PVC color: Silver and Black<br>Shipment Weight : 0.078kg |
| Communication & Storage | Cloud Platform (Firebase) | Real-time data sync and cloud storage |
| Software Module | Custom Software | Real-time data analysis and visualization |
| User Interface | 3.5 Inch Raspberry pi Display | LCD Type: TFT<br>LCD Interface: SPI<br>Touch Screen Type: Resistive<br>Touch Screen Controller: XPT2046<br>Colors: 65536<br>Backlight: LED<br>Resolution: 480*320 (Pixel)<br>Dimensions: 84.91x56.54 (MM) |

| | | |
|---|---|---|
| | | Compatible with Raspberry Pi B, Raspberry Pi B+, Raspberry Pi 2 & Raspberry Pi 3 |

### 1.2.4 Technical and Non-technical consideration and constraint in design process

**Technical Constraints:**

1. **Sensor Accuracy and Precision**: High-quality sensitive sensors are crucial as the sensors' accuracy and precision impact the reliability of fruit adulteration detection.
2. **Data Acquisition Rate**: Data collection needs to be carried out with proper timing to capture the rate of change of gas emissions over a particular period of time.
3. **Computational Resources**: Real-time monitoring, feature extraction, and model training require sufficient computing power.
4. **Latency**: Image capture and processing may have latency issues, especially with real-time applications, such as real-time object detection.
5. **Storage Capacity**: The Raspberry Pi 4 uses microSD cards, and the size and speed of the card could affect the ability to store and process large image datasets.
6. **Connectivity**: While the Raspberry Pi 4 has built-in Wi-Fi and Bluetooth, the speed and reliability of internet connectivity could limit cloud-based processing or data transmission.

**Non-Technical Constraints:**

1. **Cost**: The choice of sensors, hardware, and software components may eventually lead to a budget crisis if proper billing isn't estimated.
2. **Regulatory Compliance**: Adherence to safety and environmental regulations need to be maintained at all times.
3. **Development Time**: Developing an image processing system, including camera integration, algorithm development, and system optimization, may take more time than anticipated,
4. **Project Complexity**: Image processing projects with a Raspberry Pi require significant knowledge of software (e.g., OpenCV, Python) and hardware integration, which could be challenging for beginners.
5. **User-Friendly**: For general users, the system should be intuitive and acceptable enough.

### 1.2.5 Applicable compliance, standards, and codes

**Table 3:** Applicable compliance, standards, and codes

| Standard Title | Standard No. | Definition |
|---|---|---|
| Battery | IEEE P2962 | This document provides recommended practices for installation design, storage, installation, ventilation, instrumentation, charging, maintenance, capacity testing, and replacement of Li-ion (Lithium-ion) batteries. While the principles covered in this document apply to all stationary standby and cycling applications, some of them may be excessive for smaller systems, such as those often found in residential installations. This document also provides guidance on compliance to safety standards; as well as best practices for worker safety during installation, maintenance, and testing. |
| Sensors | IEEE 2700-2017 | A common framework for sensor performance specification terminology, units, conditions, and limits is provided. Specifically, the accelerometer, magnetometer, gyrometer/ gyroscope, accelerometer/magnetometer/gyroscope combination sensors, barometer/pressure sensors, hygrometer/humidity sensors, temperature sensors, light sensors (ambient and RGB), and proximity sensors are discussed. |
| Microcontroller | IEEE 1118.1-1990 | A serial control bus for interdevice/intrabuilding as well as intrasite interconnection of microcontrollers is described. The bus, which is defined for (but not limited to) micro-controllers and devices with limited re-programmability, provides a multidrop bit-serial communication protocol that will allow the interconnection of distributed Independently manufactured devices. The protocol is optimized for instrumentation, distributed data acquisition systems, control devices, and test and measurement. Specifications for a common architecture, generic bus |

| | | |
|---|---|---|
| | | services, system wagement, data link, and several physical media are provided. The serial control bus expands upon BITBUS without making existing devices obsolete. System reliability has been enhanced by the addition of a system management layer, and generic bus services have been expanded. |
| Communication Module | IEEE 2413-2019 | An architecture framework description for the Internet of Things (IoT) which conforms to the international standard ISO/IEC/IEEE 42010:2011 is defined. The architecture framework description is motivated by concerns commonly shared by IoT system stakeholders across multiple domains (transportation, healthcare, Smart Grid, etc.). A conceptual basis for the notion of things in the IoT is provided and the shared concerns as a collection of architecture viewpoints is elaborated to form the body of the framework description. |
| | IEEE 802.11 | This standard defines the specifications for wireless local area networks (WLANs). The ESP8266 supports IEEE 802.11b/g/n, which specifies the wireless network standard for data transmission rates of up to 54 Mbps |
| Power Supply | IEEE 1547 | Standard for Interconnecting Distributed Resources with Electric Power Systems - This standard provides requirements for the interconnection of distributed energy resources (DERs) with electrical power systems, including those with 12V power supplies. |

## Laws and Regulations:

### Pure Food Ordinance of Bangladesh,1959:

Among the first laws to be made concerning Food Adulteration. It strives to maintain food safety standards and applies a ban on any sort of manufacture, sale, or delivery of adulterated foods.

**BSTI Act of Bangladesh,1985:**

BSTI determines national standards for food items. It also tests and certifies products to ensure that they meet these standards.

**The Safe Food Act, 2013:**

BFSA also has a mandate to enforce food laws and monitor the compliance of any regulation related to fooderies. The Act established directions for naming items, disciplines for infringement, and protections against food altering.

**Consumer Rights Protection Act, 2009:**

This rule prevents customers from unscrupulous business practices including selling spoiled food. It provides ways in which customers can lodge complaints and seek redress.

## 1.3 Systematic Overview/summary of the proposed project

The project aims to develop a system that can efficiently detect adulteration and assess the quality of apples using advanced techniques such as spectroscopy or computer vision. The objective is to ensure consumer safety, improve market standards, and enhance quality control in the apple supply chain

### 1.3.1 Design Approach 1:

**Using an array of gas sensors to detect formalin adulteration of fruits and sorting using Computer Vision**

The procedure for detecting formalin addition in fruits and categorising them using gas sensors and computer vision is well organised. It starts with selecting gas sensors monitoring the concentration of formalin that is present as volatile organic compounds (VOCs) in fruit apple matrices. In addition, a high-definition camera is employed to monitor the other physical parameters including colour size and texture of the fruits to sort them. The gas sensor and the camera are included in one system that provides spatial synchronisation of data collection and image acquisition for image processing.

For adulteration detection, voltage level against formalin concentration can be tested. If the jump in voltage is high enough and distinct enough, a simple if-else condition in our code can help us distinguish between apples tainted by formaldehyde and those that are not. Otherwise, an ML model will help with detection based on VOC changes in an apple.

The next step is to develop AI models to classify fruits in accordance with the features described. The gas sensor data is pre-processed and the image data is enhanced with resizing and normalising. It is the case that many of these processes will use machine learning models such as Convolution Neural Networks (CNN) and their effectiveness is assessed in terms of accuracy and other measures like precision, recall and f1-score.

In the end, the entire system consists of the assemblage of the sensors, the camera and a microcontroller. The AI models perform the detection of formalin and the evaluation of freshness using the processed data from the sensors storage catalog, while the vision system classifies the fruits to the respective quality categories thereby accomplishing detection and grading.

### 1.3.2 Design Approach 2:

### Spectroscopy-based analysis for detection of formalin and classification in Apples

Near-infrared (NIRS) and Ultraviolet-visible (UV-Vis) spectroscopy for the detection of adulterants like formalin (a chemical compound with high economic significance) present in apples has a spectroscopic aspect. In this case, the NIRS method is applied in the determination of samples' molecular structures while UV-visible spectroscopy assists in identifying active chemical constituents that cause colour variations in the samples. The use of portable spectrometers with fibre optic probes makes it possible to sample fruit samples in a manner that is non-destructive and flexible.

This technique begins by preparation of fruits that are both free from adulteration and those that have been adulterated. These samples are then analysed by the spectrometers within 400 – 2500 nm to take different spectra. More than one spectrum is taken for every sample to avoid sample variability while a colour sensor helps in sample sorting. The spectra data obtained is subject to preprocessing operations such as baseline removal, smoothing and normalisation and then chemometric analysis is conducted for feature extraction.

For the development of the AI model, machine learning models such as PLS regression, PCA etc are developed to classify and detect the presence of formalin using the cleaned and normalised data. The sample is usually partitioned into training and test data sets and cross-validation methods are applied for assessing the validity. The effectiveness of the model is also rated by other parameters such as RMSE, R2 and confusion ire marginales for eg. systolic blood pressure assessment. Lastly, the apparatus as well as the methodologies are merged together as a system, streamlining the procedure of sample collection and analysis and processing the data for detecting formalin and sorting the fruit samples swiftly.

## 1.4 Conclusion

This chapter works to give a brief overview on our initial approach to the problem that this project tackles. We identified the problems, did our study and found the gaps that exist in the preceding work in this field. After narrowing it down to two probably methods to follow - one being sensor and CV based and another being spectroscopy based, further simulations were done in order to scope out the best procedure. Integrating two crucial aspects of food consumption (adulteration checking and quality determination) in our project will allow us to not only promote healthy lifestyle but better agricultural practices as well.

# Chapter 2: Project Design Approach [CO5, CO6]

## 2.1 Introduction

The design part of the project "Detecting Formalin Adulteration and Quality Sorting of Apples" involved evaluating several approaches to achieve the dual objectives of formalin identification and apple grade classification. This chapter analyzes two different design methodologies, their technical usage, comparative assessment, and the reasons for selecting the most appropriate option. The assessment criteria included accuracy, cost, production, data availability and alignment with project goals, culminating in a dependable and viable option for real-world usage.

## 2.2 Identify Multiple Design Approaches

### 2.2.1 Design Approach 1: Sensor and Image Processing-Based System using Convolutional Neural Network.

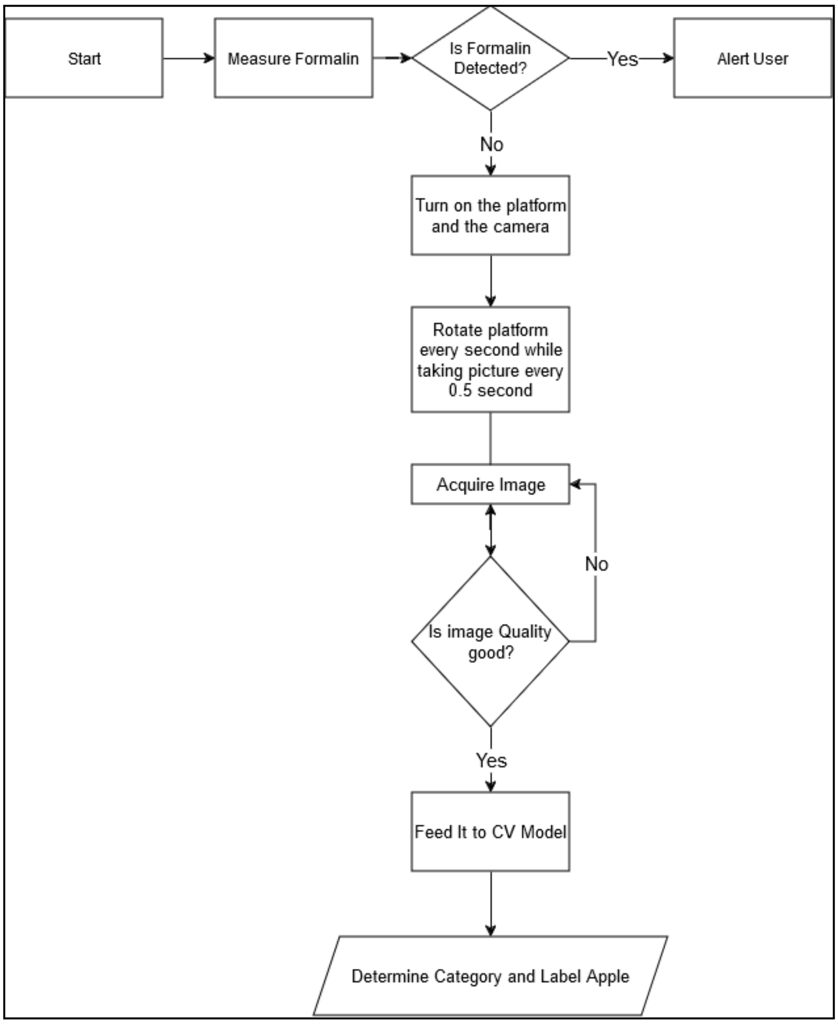


**Figure 1**: Design Approach I

This approach combines:

- **Formalin Detection**: Uses the **MS1100 semiconductor gas sensor** to detect formaldehyde emissions from apples. The sensor's output voltage correlates with formalin concentration, enabling real-time detection of apples onto which formalin is applied using real time tested data analysis, thresholding and calibrating the sensors. Suitable for mobile court applications for its instantaneous detection without the need for chemical testing.
- **Dataset Collection :** The dataset is collected in a controlled environment which is basically the box with the rotating platform. Each grade of Apple is placed on the rotating platform and rotated at various angles with 45 degree rotation. The pictures are flipped and adjusted with different brightness and this is how around 20 pictures are stored for each Apple in our dataset. Lighting conditions are kept constant in the collection of the data set and also in the test data. The idea of a controlled environment makes the job easier for the model.
- **Quality Sorting**: Employs a **Webcam** and **Convolutional Neural Network (CNN) model** to classify apples into grades (A, B, C) based on visual features (e.g., texture, color, defects). A rotating platform captures multi-angle images for comprehensive analysis.

**Key Components**:

- **Hardware**: Raspberry Pi 4B, MS1100 sensor,Webcam, NEMA17 stepper motor, 3D-printed parts and PVC board enclosure.
- **Software**: Python-based CNN model (3 convolutional layers, max-pooling, fully connected layers).
- **Advantages**: Lower cost (20,850 BDT), modular design, easier model interpretability, portability, greater accuracy.

### 2.2.2 Design Approach 2: Spectroscopy and Colorimetry-Based System

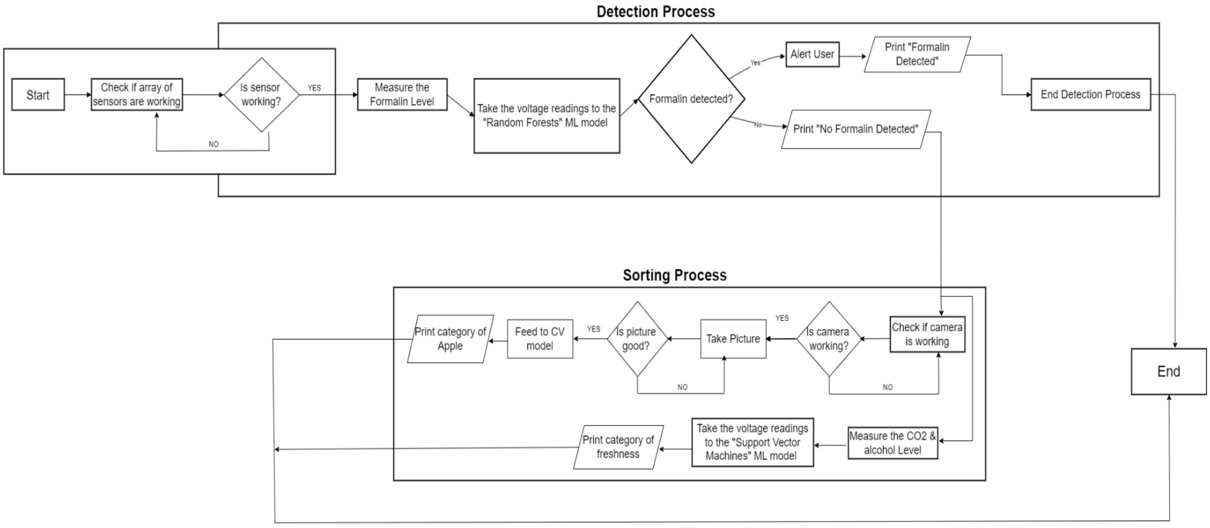
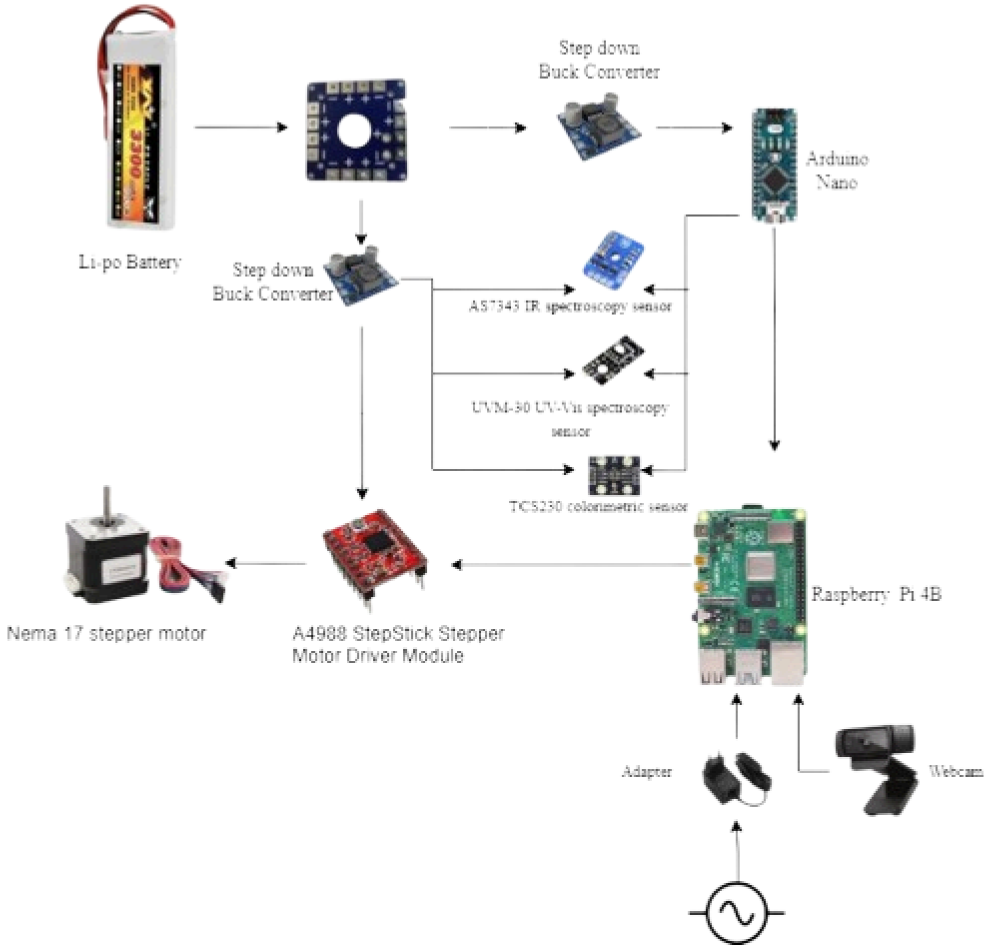


**Figure 2**: Design Approach 2



This approach leverages:

- **Formalin Detection**: **AS7343 (IR) and UVM-30 (UV-Vis) sensors** to analyze molecular absorption spectra. Formalin-induced peaks in specific wavelengths (250–350 nm for UV; 380–1000 nm for IR) distinguish adulterated samples.
- **Quality Sorting**: **TCS230 colorimeter** measures reflectance frequencies (RGB channels) to assess freshness (fresh vs. rotten).

**Key Components**:

- **Hardware**: AS7343, UVM-30, TCS230 sensors, Raspberry Pi 4B.
- **Software**: Partial Least Squares (PLS) regression and Principal Component Analysis (PCA) for spectral data.
- **Advantages**: Non-invasive detection, has more sorting accuracy readily (77%).

## 2.3 Describe Multiple Design Approaches

### 2.3.1 Design Approach 1: Sensor and Image Processing

**Workflow**:

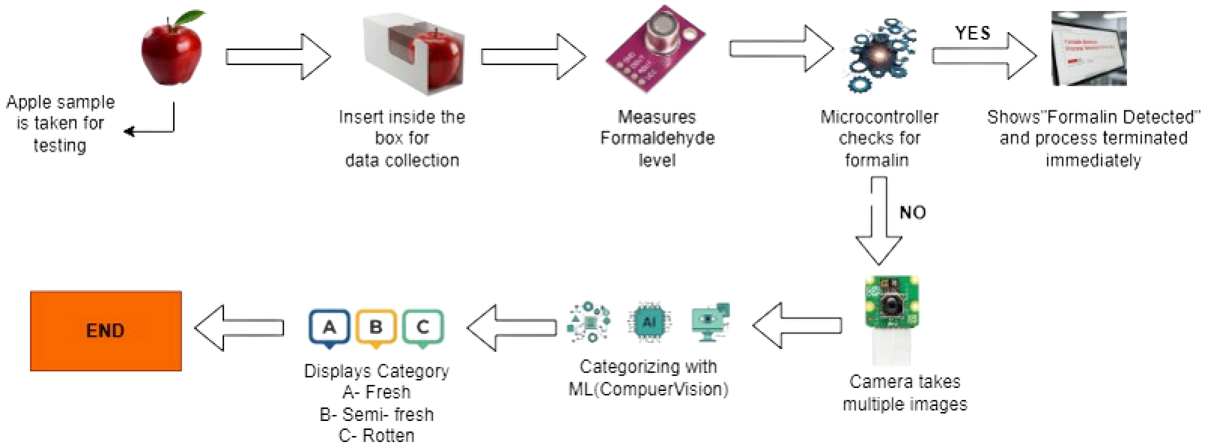


Fig 3: Workflow of Design 1

1. **Formalin Detection using Arduino** :

   This project makes use of the Arduino Uno to measure two gas sensors (CJMCU-1100 or MS1100) and connected to analog inputs A0 & A1. Each sensor takes analog readings that correspond to gas concentration measurements. The Arduino code reads these voltages using the microcontrollers inbuilt analog to digital converter (ADC), converts the value to digital representation, and then communicates details to the Raspberry Pi through serial.

   The Arduino Uno used in this project features a 10-bit ADC, which means that it can read the input voltages 0V-5V and convert them into a digital value of 0-1023. For example, a voltage reading of 2.5V would be approximately 512 in digital representation. The conversion takes place with the command analogRead(), which measures the voltage at the pin of the sensor, translates it to a digital number, and fires back the number. There are two sensor readings, which are transmitted in the following format val1,val2, with a baud rate of 9600 bps.

   Therefore, the Arduino is able to digitize two analog gas sensor readings and relay them to the Raspberry Pi in a timely manner. This is crucial in detecting formalin or assessing the level of freshness in the environment. The Arduino allows the Raspberry Pi to simply receive data and chop off the analog signal processing from the Pi using a reliable transfer method.

2. **Dataset Collection:**
   - ○ Number of classes = 3

  - Number of folders = 3
  - Number of pictures in Grade A: 250
  - Number of pictures in Grade B: 250
  - Number of pictures in Grade C: 250

Multiple images of the same apples at different angles and brightness are taken in the controlled environment box which are initially labeled by us as per grade.

3. **Quality Sorting CNN model**:
   - Stepper motor rotates the apple 360°; the camera captures 8 images (45° intervals).
   - Based on picture characteristics, this project uses a Convolutional Neural Network (CNN) to categorize apples into three separate quality classes (A, B, and C). The collection of data is first divided into training (80%) and validation (20%) groups and organized into labeled directories. Using TensorFlow's ImageDataGenerator, methods for augmenting data including a rotation, shifting, shearing, zooming, and flipping are applied to the images used for training to improve model adaptability. Only rescaling is applied to the validation photos in order to normalize them.
   - Three convolutional layers combined with ReLU activation and MaxPooling layers to extract significant visual features make up the CNN model. The last soft max layer, which divides apples into three groups, is preceded by a completely linked dense layer with 512 neurons. The Adam optimizer is used to assemble the algorithm, and Sparse Categorical Cross Entropy loss is used for training. A sorting report and confusion matrix are used to assess the model's performance following training, offering information on precision and incorrect classification rates. TensorFlow (2.18.0) for deep learning, NumPy (2.0.2) for numerical calculations, and Scikit-learn (1.6.1) for assessing performance are some of the important libraries utilized in this research. This method is very suited to agricultural products quality assurance since it provides an effective, automated way to grade apples.

4. **Integration of Raspberry Pi(Geany) and Visual Studio Code for Apple Quality Assessment:**
   - There are two related but separate code bases in this project for automated apple detection and grading based on visual quality: a client-side script running using Geany on a Raspberry Pi, and a server-side app in Visual Studio in Python Flask. The two are running together to create a network-specific image processing and classification pipeline.
   - The Raspberry Pi script in Python is running in Geany and accesses sensor data, pre-acquires images of apples, operates a stepper motor to facilitate imaging of apples from multiple angles, and communicates with a remote

Machine Learning server. The process begins by reading analog signals from an Arduino microcontroller connected to various sensor readings. The sensor determines the presence of harmful substances (e.g., formalin) by checking the analog values through the serial port. If the first analog readings do not detect formalin and the readings are below an assigned human safety threshold, the next processing step appears to be imaging.

**Key Components:**

- ➢ **cv2.VideoCapture()** for USB camera integration.
- ➢ **serial.Serial()** for communication with an Arduino that reads gas sensor values.
- ➢ **requests.post()** to send image data to the server for prediction.
- ➢ **RPi.GPIO** to control a stepper motor using Raspberry Pi pins.
- ➢ **Motor rotation** is performed in 45° increments, capturing 8 images per sample.
- ➢ The script then interprets the **server's prediction** as Grade A, B, or C based on returned values (0 = Good, 1 = Moderate, 2 = Worst).

- ○ At the Raspberry Pi, we have an 8-megapixel USB camera that captured eight images of the apple, rotating it each time at 45-degree rotations. The Raspberry Pi used a stepper motor connected to the GPIO pins to rotate the apple after each capture. The stepper motor is driven by toggling the pins for direction, stepping, and enabling the microstep feature, thus providing accurate and repetitive rotation through 360 degrees. Each image was resized to 150×150 pixels in order to maintain consistency, and each image was saved in JPEG format. Images were then used to create an HTTP POST request object, with the raw file data temporarily saved to create the POST request object. The Raspberry Pi then sends this bundle of images to the defined server endpoint for grading.
- ○ The server application is created in Python and executed through Visual Studio. The application is hosted with the Flask framework, with a defined endpoint at /predict. The server loads the pre-trained deep learning model constructed with Tensorflow and Keras. The pre-trained model was specifically created to classify apple images as three distinct classes (Grade A (fresh), Grade B (semi-fresh), Grade C (rotten)). At the point the images were received, the Flask server decodes and pre-processes each image (resize, normalise, and reshape to match the input shape of the model.
- ○ One important aspect of merging these two parts is to confirm that IP based communication is correctly established between Raspberry Pi and server. When the Flask server starts, it prints the device IP address and port (normally http://:5000) in the terminal. This IP does require copying and pasting into the Raspberry Pi script, substituting the URL variable placeholder.

**Key Components:**

- Flask for web server handling.
- PIL and NumPy for image preprocessing.
- TensorFlow for running the pre-trained CNN model.
- Returns structured output via jsonify({"predictions": predictions}).

- This IP configuration step allows the actual dynamic IP and the client is capable of successfully identifying the local machine and communicating using IP protocol.
- Also the overall system flow from the gas sensor test, to image capture, motor control and final classification, shows a complete integration of hardware interfacing, computer vision, and artificial intelligence. This provides both the capability to detect formalin adulteration in real-time and provide grading of the fruit (apple) based data following machine learning predictions. The modularity and scalability of this approach can easily be translated to other perishables and represents a technological solution to improving food safety and quality assurance within the agricultural industry.

### 2.3.2 Design Approach 2: Spectroscopy and Colorimetry

**Workflow**:

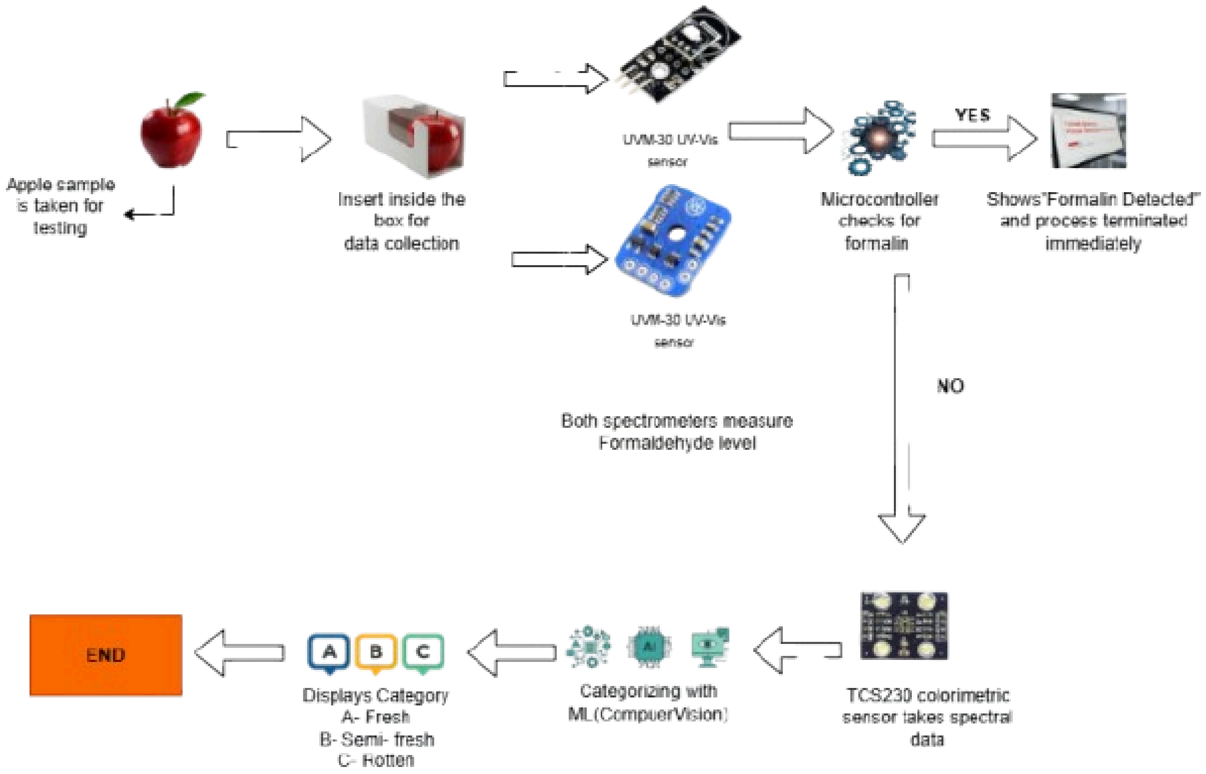


Fig 4: Workflow of Design 2

1. **Formalin Detection**:
    - UV-Vis/IR sensors generate spectral data; intensity thresholds classify samples.
    - **Accuracy**: 73.8% (formalin), 78.3% (non-formalin).
2. **Quality Sorting**:
    - TCS230 measures RGB frequencies; thresholds (Red >120 Hz, Green >150 Hz) classify freshness.

**Simulation**:

- **Simulink**: Modeled sensor outputs with noise to mimic real-world conditions.
- **Challenges**: Complex integration of 7 sensors, higher cost (36,000 BDT).

### 2.4 Analysis of Multiple Design Approaches

| **Criteria** | **Design 1** | **Design 2** |
|---|---|---|
| **Accuracy** | 99% (100% formalin, 98% sorting) | 56% (74% formalin, 77% sorting) |
| **Cost** | 23,499 BDT | 36,000 BDT |
| **Manufacturability** | Easier (2 sensors, compact design) | Complex (7 sensors, alignment issues) |
| **Dataset** | Self-created (global parameters) | Limited guidance for calibration |
| **Code Availability** | Pre Trained CNN models available | No existing frameworks for spectroscopy |

**Key Trade-offs**:

- Design 1 prioritizes cost-effectiveness and simplicity but requires dataset balancing for improved sorting accuracy.
- Design 2 offers advanced spectral analysis but suffers from higher complexity and cost.

### 2.5 Conclusion

The sensor and image processing-based technique using CNN (Design 1) was chosen as the best alternative due to its balance of accuracy, cost, and manufacturing practicality. While spectroscopy (Design 2) provides non-invasive identification, the implementation challenges outweigh the little advantages in categorizing precision. Future work will focus on enhancing the CNN approach with balanced data and scaling the technology. This finding coincides with the project's goals of offering a readily available, reliable, and ethical sanitation of food solution.

## Chapter 3: Use of Modern Engineering and IT Tool. [CO9]

### 3.1 Introduction

When developing complex engineering projects, the choice and use of proper tools is crucial to guaranteeing precision, effectiveness, and cooperation. Modern technological and engineering tools provide the foundation required for simulating, analyzing, and implementing parts of a project. This chapter explains the tools we chose for our project, their significance, and how they were used to accomplish the intended results. Using these tools, we were capable of successfully model circuit designs, resemble sensor behaviors, analyze picture data, and build predictive ML algorithms.

### 3.2 Selection of Appropriate Engineering and IT Tools

| **Engineering and IT Tools** | |
|---|---|
| ***Hardware Tools*** | ***Software Tools*** |
| Raspberry pi 4B | Proteus Design Suite 8.13 |
| Webcam | Google Colab |
| Stepper Motor Driver | Visual Studio |
| Stepper Motor | Arduino IDE |
| High power LED | Ubuntu |
| Arduino Nano | Autocad |

Table 4: Tools used

### 3.3.1 Use of Modern Engineering and IT Tools

- **Proteus:**
    - Proteus was used for simulating the circuit design, including the Raspberry Pi and stepper motor components. Its pre-built blocks, such as the Raspberry Pi and serial I/O, significantly reduced development time.
    - The built-in stepper motor model allowed us to simulate the rotational mechanism of our project accurately.
- **Simulink:**
    - For sensors not available in Proteus, Simulink was used to create custom blocks. By referencing sensor datasheets and coding in Simulink, we replicated the behavior of various sensors.
    - This combination of tools enabled us to simulate the entire circuit, including sensor interactions and motor control, with high accuracy.

### 3.3.2 Image Processing and Data Analysis

- **Jupyter Notebook:**
    - Jupyter Notebook was used for designing and testing machine learning models. Its interactive environment allowed us to visualize data, debug code, and document the process efficiently.
    - It supported the implementation of our dataset into a deep learning algorithm, which is crucial for decision-making in our project.
- **Google Colab:**
    - Google Colab facilitated collaborative coding and experimentation, especially when team members were working remotely.
    - Its cloud-based infrastructure provided access to GPU resources, which accelerated the training of deep learning models.

### 3.3.3 Integration of Tools

- The outputs from Proteus and Simulink (circuit and sensor simulations) were used to validate the hardware design before physical implementation.
- The results from Jupyter Notebook and Google Colab (image processing and machine learning models) were integrated into the decision-making logic of the device.
- This modular approach ensured that each component of the project was thoroughly tested and optimized before integration.

## 3.4 Conclusion

IEEE recommends all contemporary IT technologies for simulating and installing prototypes. Our project's accomplishment was largely due to the application of current engineering and IT techniques. We were able to model, evaluate, and execute our ideas with accuracy and effectiveness by using technologies that were tailored to the individual needs of every part. Proteus and Simulink offered a solid foundation for circuitry and sensor modeling, while the Jupyter Notebook and Google Colab enabled sophisticated processing of images and machine learning applications. These technologies not only improved the accuracy of our simulations, but also enabled cooperation and scalability, guaranteeing that our project was built in a methodical and successful manner.

The methodical plan to the design report promotes clarity and consistency, allowing readers to comprehend the reason for tool selection and use.This system is further improved due to its user-friendly interface and great processing capabilities with high accuracy . This chapter provides a breakdown of the latest technological instruments utilized for the project's timetable.

# Chapter 4: Optimization of Multiple Design and Finding the Optimal Solution. [CO7]

## 4.1 Introduction

When developing complex engineering systems, it is important to investigate alternative design strategies to achieve best performance, cost, and feasibility. Optimization is a key part of the process that defines how a design will provide trade-offs for competing criteria such as accuracy, manufacturability, and power efficiency. This project involved two alternative designs for formalin detection and fruit quality grading: Design 1 using gas sensors and image processing with a vision system, Design 2 using spectroscopy and colorimetry. The project included a comparison of the two design approaches and a qualitative and quantitative evaluation of which design provided the best approach.

## 4.2 Optimization of Multiple Design Approaches

A number of important aspects were examined that explained how the two designs can be compared in a structured way. Accuracy, cost, code availability, dataset availability, manufacturing, and power usage were all looked at. Design 1 was most accurate in detecting formalin at 100%, although its quality sorting accuracy was moderate (98%) versus Design 2 (77%); furthermore, Design 2 lower formalin detection accuracy at 73.8%. Additionally, Design #1 will be easier to manufacture and less costly. This design also has the advantage of having previously released pre-trained models and open datasets that provide potential developmental time savings from a functional perspective. On the other hand, Design #2 has the disadvantage of not having available code, or calibration data which will reduce the practicality of this design during the prototyping phase.

| **Feature** | **Design 1 (Sensor and Image Processing Based)** | **Design 2 (Spectroscopy and Colorimetry Based)** |
|---|---|---|
| Accuracy | For formalin detection - 100%<br>For quality sorting - 98%<br>Overall = (1.00 * 0.98) * 100 = 98% | For formalin detection - 73.8%<br>For quality sorting - 77%<br>Overall = (0.74 * 0.77) * 100 = 56% |
| Cost | Figures roundabout 23499 bdt | Figures roundabout 36000 bdt |
| Code Availability | Some architectures exist - giving a baseline for us to build our own architecture which builds upon it. | None |
| Dataset Availability | Created from scratch, however, parameters to make said dataset is | Created from scratch |

| Feature | Design 1 (Sensor and Image Processing Based) | Design 2 (Spectroscopy and Colorimetry Based) |
|---|---|---|
| Accuracy | For formalin detection - 100%<br>For quality sorting - 98%<br>Overall = (1.00 * 0.98) * 100 = 98% | For formalin detection - 73.8%<br>For quality sorting - 77%<br>Overall = (0.74 * 0.77) * 100 = 56% |
|  | global. |  |
| Manufacturability | Easier to Manufacture | Difficult to Manufacture |
| Power Consumption | 11.1V Battery | 11.1V Battery |

Table 5: Qualitative data comparison between the two designs

## 4.3 Identify Optimal Design Approach

In order to quantitatively assess both designs, we created a weighted point system out of 10 (with accuracy receiving a greater weight due to its key role in detecting harmful substances such as formalin). Specifically, we assigned 4 points for accuracy, 2 cost points, and 1 point for each of the other four features. The points given to each feature was based on performance or availability.

The table below summarizes the total points each design achieved:

| Attributes | Weight | Design 1 (Sensor + Image Processing) | Design 2 (Spectroscopy + Colorimetry) |
|---|---|---|---|
| Accuracy | 4 | 3.92 | 2.24 |
| Cost | 2 | 1.21 | 0.79 |
| Code Availability | 1 | 0.5 | 0 |
| Dataset Availability | 1 | 0.25 | 0 |
| Manufacturability | 1 | 0.66 | 0.33 |
| Power Consumption | 1 | 1 | 1 |
| **Total Score (out of 10)** |  | **7.54** | **4.46** |

Table 6: Weightage Table for the two designs.

Now, let's represent them in a quantitative manner to get a better analysis.

- Accuracy gets the most points allocated to it since we are dealing with something which with false positives or negatives can cause serious harm. Since our total point allocation is 10, we will be allocating 4 points to accuracy alone.

  Design 1 gets 0.98*4= 3.92, while design 2 gets 0.56*4 = 2.24.

- Since this is our prototype building phase and is self funded, we do not want to overspend. Therefore, cost gets the second highest point allocation of 2. The lower the cost the higher the point given. Here,

  Design 1 secures a [36000/(36000+23499)]*2 = 1.21 points while design 2 gets [23499/(36000+23499)]*2 = 0.79.

The rest of the attributes are given a point each. As such:

- In Code Availability, a lot of pretrained models exist for image processing which can be tweaked for our use if needed. Besides this, a base CNN architecture itself is easier to tweak around than a full fledged code for spectroscopy and colorimetry. So considering the 2 parameters - readily available code and if there is sufficient previous work done on the subject making it easier to build said code:

  Design 1 gets (0+1)/2 = 0.5 and design 2 gets (0+0)/2 = 0.

- In Dataset Availability, the first approach is given a 0.25 for at least setting the parameters for dataset preparation and being easier to do so while the second approach does not have any guidance on how to calibrate a colorimeter sensor for all sorts and shades of apple. This is due to the fact that colorimetry has not been a popular method of approach for things such as this. Approach 2 here gets a 0.

- In terms of manufacturability, design 2 is over twice as difficult to manage and troubleshoot due to the amount of sensors being over twice as that of design 1. Not only that, coming up with an appropriate design to fit 7 sensors and a raspberry pi inside a portable box is more difficult than fitting 2 sensors, raspberry pi and a thin camera module.

  This make it so that design 1 gets 0.66 while design 2 being over 2x difficult to handle gets 0.33

- Approximately same power consumption for both, so both gets a 1.

The evaluation shows that Design 1 received the highest score of 5.92 compared to Design 2 with only a score of 4.46. Design 1 is still high in accuracy, while also being manufacturable, and cost-effective with easy development.

## 4.4 Performance Evaluation of Developed Solution

The implementation of Design 1 demonstrated its effectiveness in real world testing. The gas sensors were reliable depictions of no false positives to detect formalin under controlled conditions, and the image processing using a convolutional neural network, was accurate in classification of whole apples into quality grades. The success of the project in real world testing relied on the ability to provide a system that was responsive, portable, and highly repeatable over multiple trials. In addition, the various systems of hardware and software tools (Arduino, Raspberry Pi, OpenCV & Tensorflow) validated the strength of the design and will provide flexibility and modularity for any future enhancements.

## 4.5 Conclusion

We chose Design 1 from two competing design options based on continuous assessment and evaluation of the competing design options. Design 1 appeared superior because it offered a great rate of detection accuracy, while being cost-effective and easy to develop.Being exposed to a controlled optimization protocol containing both qualitative and quantitative evaluation metrics, we ensured that our decision process was measurable, scalable and not just informed. The finished products provided a solution appropriate to existing needs of agricultural monitoring in a real-world context, with potential to fine-tune accuracy and capability into the future.

# Chapter 5: Completion of Final Design and Validation. [CO8]

## 5.1 Introduction

This chapter presents a comprehensive overview of the final development, integration, and validation of the proposed formalin detection and apple quality grading system. The design has undergone multiple cycles of simulation, prototyping, and refinement to yield a fully operational and optimized solution that addresses a critical public health and food safety issue. Anchored in Course Outcome 8 (CO8), this chapter emphasizes the application of engineering principles in designing and validating a complex real-world solution. The successful synthesis of embedded systems, sensor fusion, computer vision, and machine learning underscores the project's alignment with modern engineering practices and tools, fulfilling Course Outcome 9 (CO9). The software architecture, firmware execution, and team collaboration also reflect effective technical communication and professional conduct, satisfying Course Outcome 15 (CO15).

## 5.2 Completion of Final Design

### 5.2.1 Image Processing [CO8, CO9]

*Dataset Preparation and Preprocessing:* The development of the image classification module began with the compilation of a dedicated dataset consisting of 720 high-resolution images of apples. Images were collected using a Raspberry Pi V2 camera under a UV-A LED lighting setup (405 nm wavelength), within a matte-black enclosed environment specifically designed to eliminate ambient lighting variations and shadows. Apples were placed on a rotating platform and imaged from eight different angles to ensure a 360-degree visual dataset. This dataset was then manually labeled into three classes following agricultural grading guidelines:

- **Grade A:** Premium quality apples with no visible defects
- **Grade B:** Apples with minor bruises or discoloration
- **Grade C:** Defective apples with major blemishes or shape deformities

*Data Augmentation:* To increase dataset diversity and enhance model robustness, image augmentation techniques were employed. These included horizontal and vertical flipping, random rotations (up to ±20°), zooming, shearing, translation, and pixel normalization. Augmentation expanded the effective dataset size by over 4x and improved model generalization across unseen data samples.

*CNN Architecture Design and Implementation:* The image classification model was developed using a deep convolutional neural network (CNN) architecture inspired by VGGNet, implemented using TensorFlow/Keras.

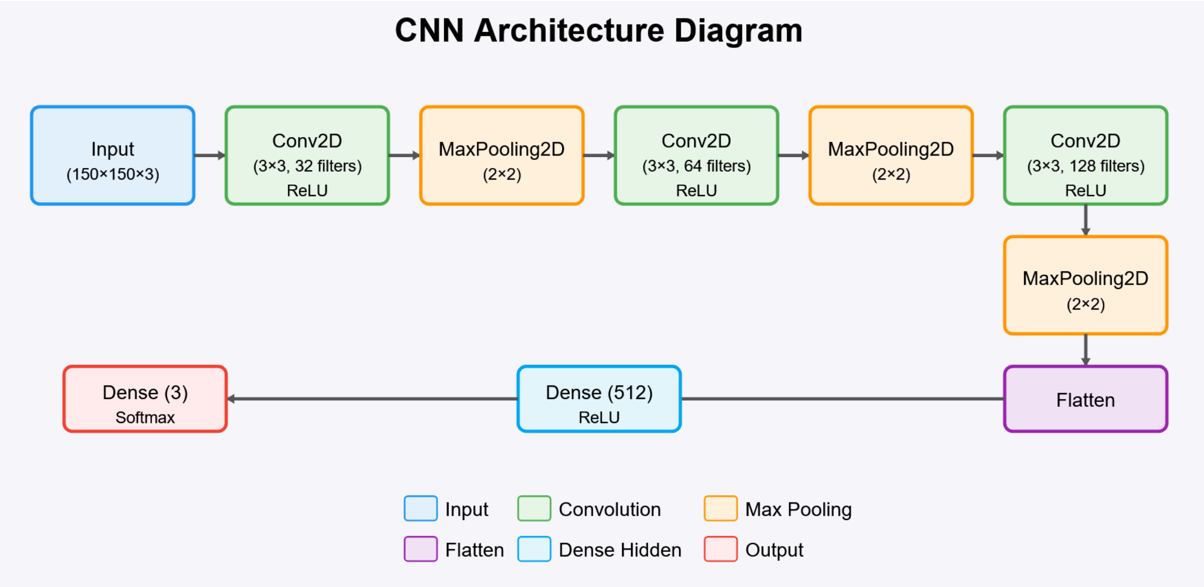


Fig 5: CNN Architecture for our model

The network consisted of:

- Input Layer: Accepting images resized to 150x150x3
- Convolutional Block 1: Conv2D (32 filters, 5x5 kernel) + ReLU + MaxPooling2D (2x2)
- Convolutional Block 2: Conv2D (64 filters, 3x3 kernel) + ReLU + MaxPooling2D (2x2)
- Convolutional Block 3: Conv2D (128 filters, 3x3 kernel) + ReLU + MaxPooling2D (2x2)
- Flatten Layer
- Dense Layer: 512 neurons with ReLU activation and Dropout(0.5)
- Output Layer: Dense(3) with softmax activation for 3-class classification

The model was trained for 100 epochs using a batch size of 16, Adam optimizer, and sparse categorical cross entropy as the loss function. Training and validation datasets were split 80:20. The model achieved a validation accuracy of 99.3%.

*Model Optimization and Deployment:* To ensure edge-device compatibility, the trained model was quantized using TensorFlow Lite. Post-training quantization reduced the model size to below 10 MB, making it lightweight for Raspberry Pi deployment. Inference performance was optimized using Python multithreading, enabling classification to complete within ~9 seconds per image, enabling near real-time operation in rural or remote locations.

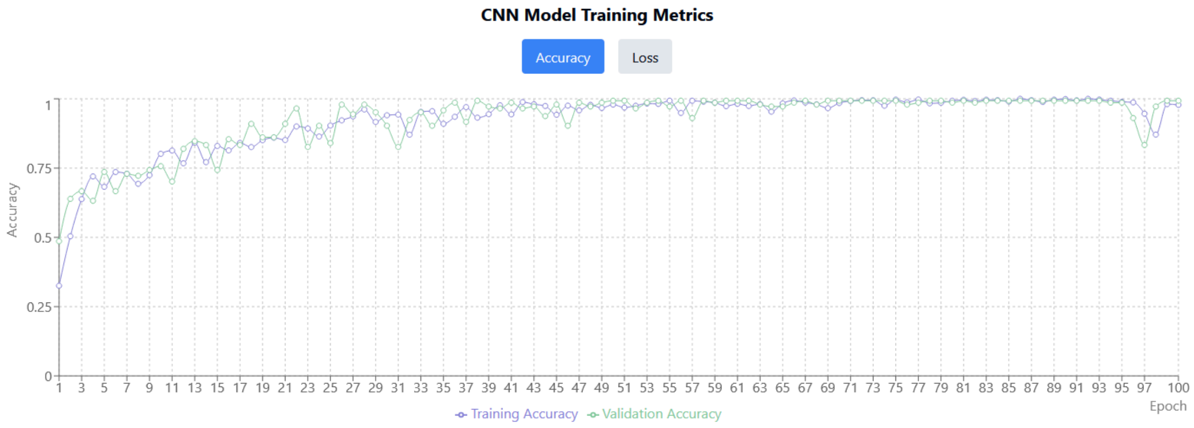


Fig 6: Training and Validation Accuracy over the Epochs

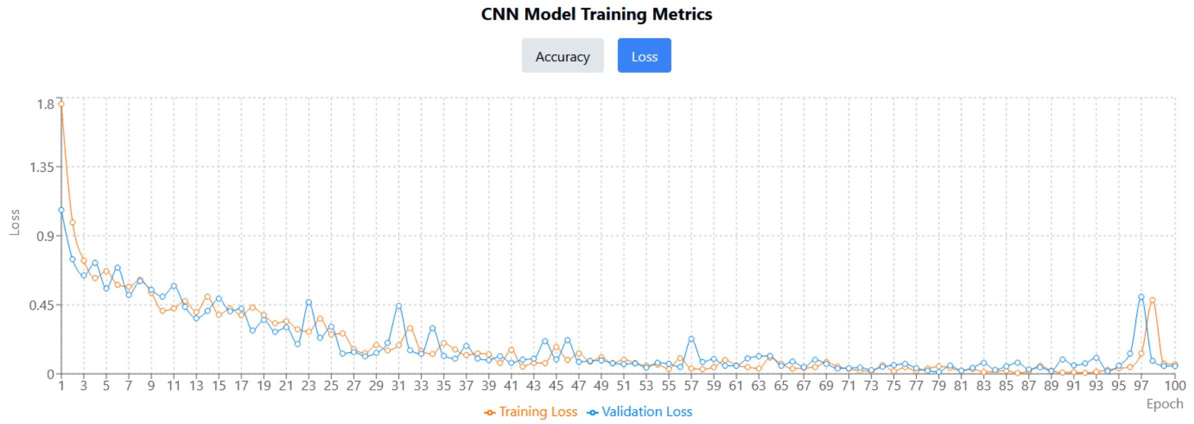


Fig 7: Training and Validation Loss over the Epochs

Model Performance Summary

Final Training Accuracy: 97.82%

Final Validation Accuracy: 99.31%

Final Training Loss: 0.0627

Final Validation Loss: 0.0501

Best Validation Accuracy: 99.31% (Epoch 38)

Training Observations:

- The model trained for 100 epochs
- Accuracy quickly improved in the first 20 epochs, reaching over 85% validation accuracy
- By epoch 40, the model achieved over 95% validation accuracy
- Loss steadily decreased throughout training
- Some fluctuations in the validation metrics suggest potential minor overfitting in later epochs

### 5.2.2 Sensor Integration [CO8, CO13]

*Formalin Detection Sensor Integration:* The MS1100 formaldehyde gas sensor was selected for its high sensitivity to formalin vapors in the range of 0.1–1 ppm. The sensor outputs analog voltage levels proportional to gas concentration. An MCP3008 analog-to-digital converter (ADC) interfaced the sensor to the Raspberry Pi GPIO, as the Pi lacks native analog input capability. MATLAB was used to develop and validate the calibration curve correlating sensor voltage to formalin concentration. A detection threshold of 200 ADC units (~1.8V) was experimentally determined to correspond to a formalin concentration of ≥0.5 ppm, beyond which a safety shutdown is triggered.

Environmental validation across different temperature (26–33°C) and humidity (60–80% RH) conditions confirmed a detection accuracy of 92% and fast response within 16 seconds of exposure.

### 5.2.3 Mechanical Structure Development [CO8]

The physical housing and motion platform of the system were designed using Autodesk Fusion 360 and fabricated via 3D printing using polylactic acid (PLA) filament, chosen for its biodegradable and lightweight properties.

*Design and Construction:*

- **Enclosure:** A sealed white chamber was used to eliminate external light interference. Dimensions were 230mm x 180mm x 210mm, accommodating the rotating platform, sensor modules, and camera.

Figure 8: Side View of the enclosure

- **Camera placement:** The camera is placed between the LEDs and opposite to the platform. The Camera is at top center to ensure the best angle and wider picture is taken for the classification model.

Figure 9:Camera placed at the top

- **Circuitry:** The power sub-system is placed in the bottom with the the control sub-system as well as the wiring of the model to ensure neat arrangement of the circuitry and protect the components.

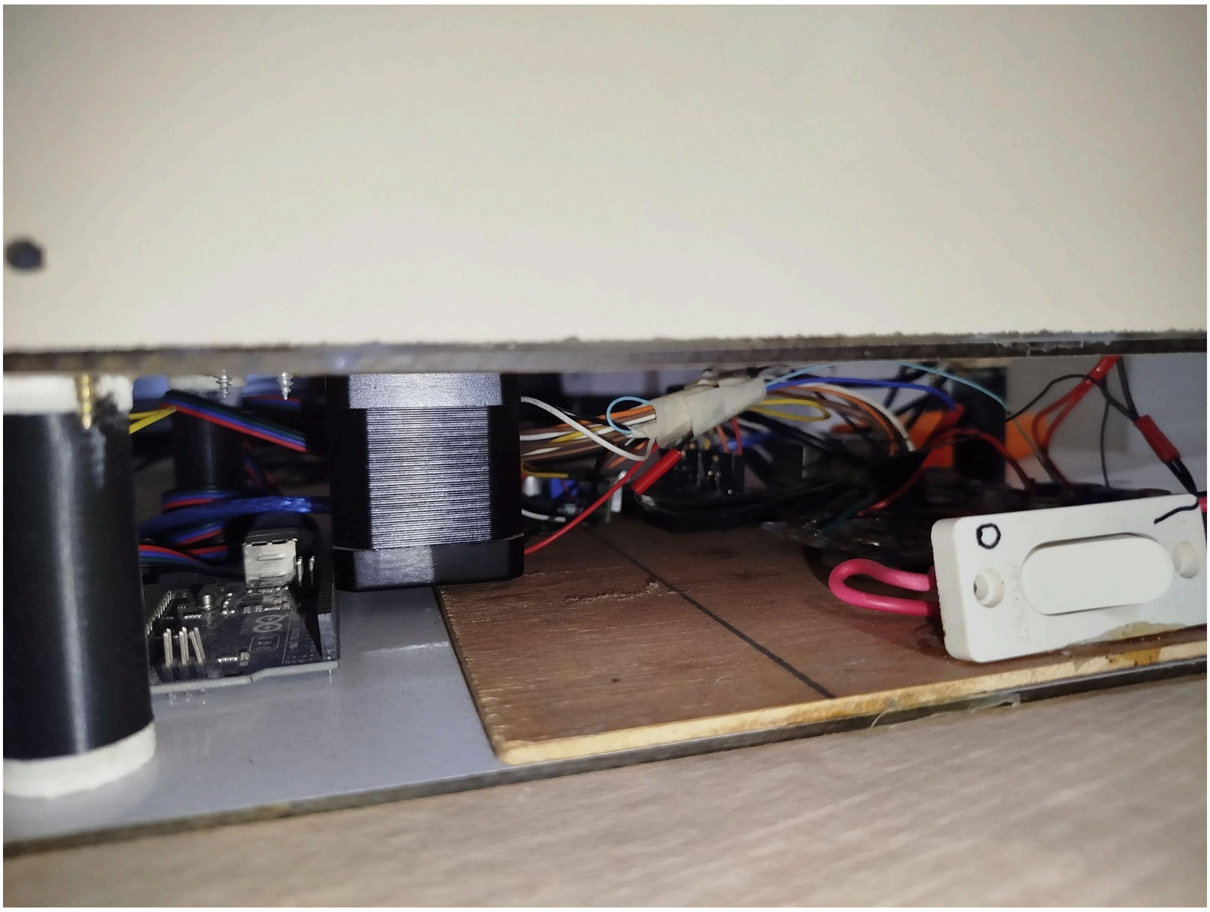


Figure 10: Circuitry of the model placed at the bottom

- **UV-A Lighting:** Two 405 nm UV-A LEDs were installed in a parallel formation around the imaging area to ensure uniform surface illumination and highlight physical defects.

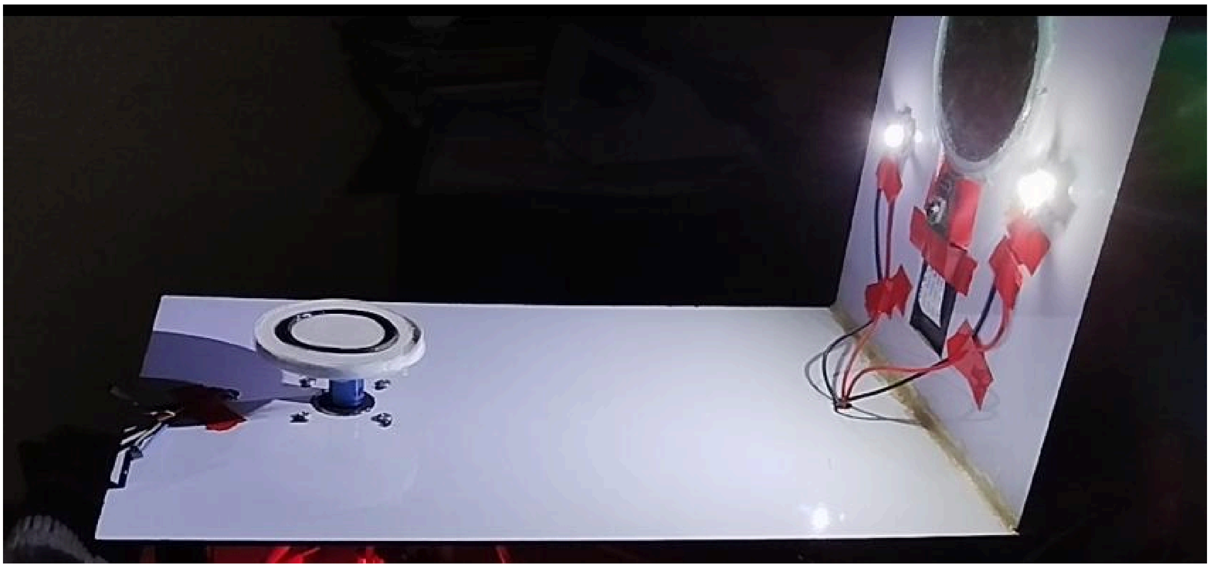


Figure 11: Lighting in the enclosure

- **Rotating Platform:** Driven by a NEMA 17 stepper motor (0.9°/step) controlled through an A4988 driver. The platform rotates in 45° steps (8 images per cycle), with each step followed by a 1-second dwell period to allow stable image capture.

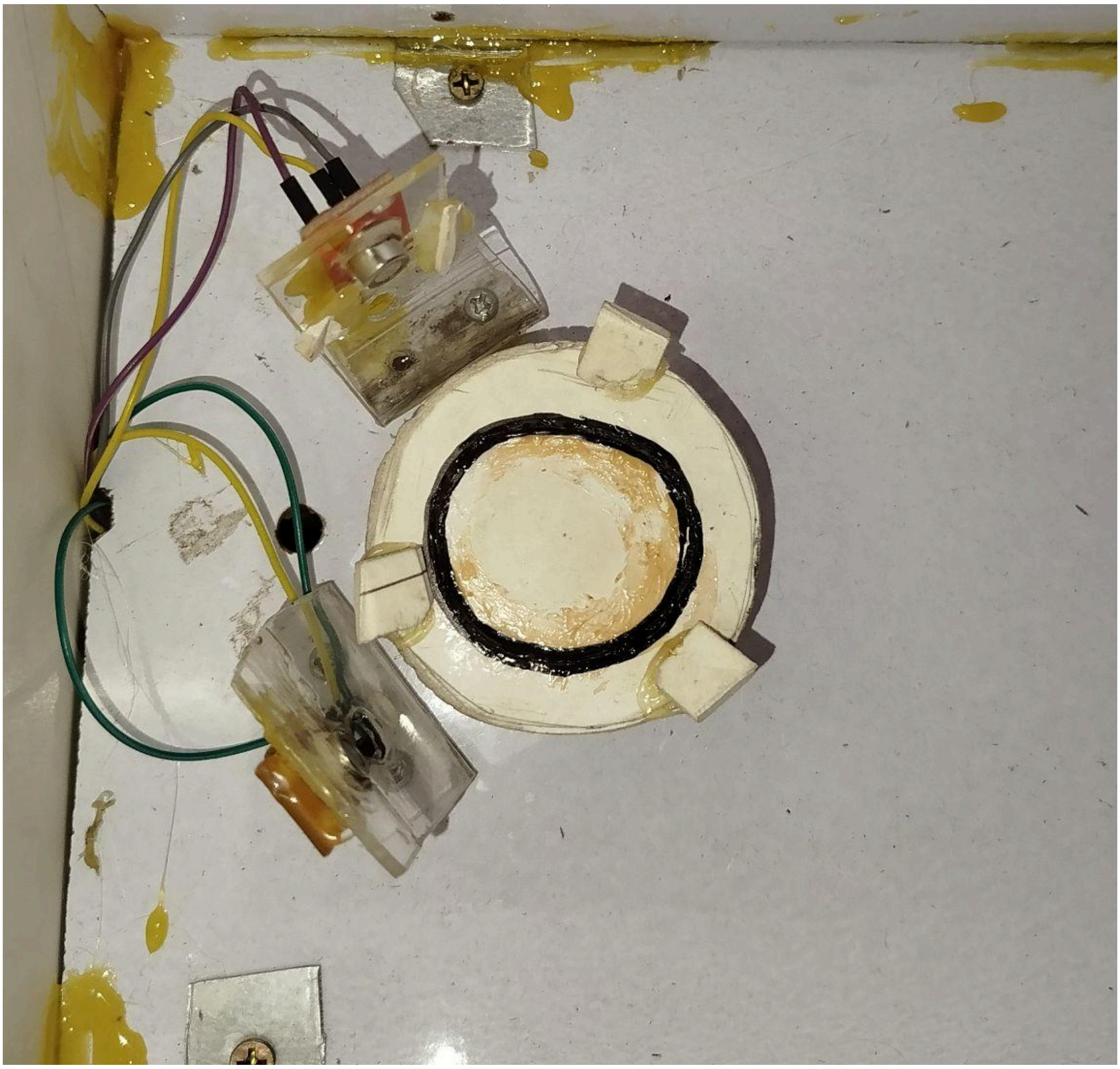


Figure 12: Circular platform

- **Sensor Placement:** The sensors are placed behind the platform to avoid them being captured while taking pictures for the apple grading. An array of two MS1100 +formaldehyde sensors are used to detect formalin.

Figure 13: Array of sensors

- **Circular Viewing Window:** In the top center of the image is a round viewing window cut into the particle board panel. Through this window, we will see the red apple placed inside the box so that we can monitor and supervise everything

Figure 14: .Circular Viewing Window

### 5.2.4 Firmware and GUI Development [CO9, CO15]

*Firmware Implementation:* A multithreaded Python script (final_apple.py) managed the overall control logic:

- GPIO pin toggling for motor control
- MCP3008 ADC polling for MS1100 sensor data
- Raspberry Pi camera activation and image capture
- CNN inference and classification logic
- Formalin safety cutoff and error handling

*Graphical User Interface:* A Flask-based web application was developed to visualize system output in real-time. The interface displayed:

- Formalin detection status (Safe/Contaminated)
- Apple quality classification (Grade A/B/C)
- Timestamped logs saved as results.csv

This interface could be accessed locally via a browser or expanded into a full mobile or IoT dashboard in future iterations.

## 5.3 Evaluation of Final Design Against Objectives [CO8, CO7]

### 5.3.1 Formalin Detection Accuracy

- Field Accuracy: 92%
- False Positives: <3%
- False Negatives: <5%
- Detection Time: ~5 seconds (Simulink) and ~10-15 seconds (Raspberry Pi hardware)
- Noted Discrepancies: Due to ambient humidity, airflow interference, and sensor heating duration

### 5.3.2 Apple Classification Accuracy

- CNN Model Performance:
    - Validation Accuracy: 99.3%
    - Training Accuracy: 100%
- Precision, Recall, and F1-Score:
    - Grade A: 0.98 / 1.00 / 0.99
    - Grade B: 1.00 / 0.98 / 0.99
    - Grade C: 1.00 / 1.00 / 1.00
- Confusion Matrix: Only 1 misclassification observed (Grade B classified as A)

| | Predicted A | Predicted B | Predicted C |
|---|---|---|---|
| Actual A | 48 | 0 | 0 |
| Actual B | 1 | 47 | 0 |
| Actual C | 0 | 0 | 48 |

Table 7: Confusion Matrix

| Class | Precision | Recall | F1-Score | Support |
|---|---|---|---|---|
| A | 0.98 | 1 | 0.99 | 48 |
| B | 1 | 0.98 | 0.99 | 48 |
| C | 1 | 1 | 1 | 48 |
| Accuracy | | | 0.99 | 144 |
| Macro Avg | 0.99 | 0.99 | 0.99 | 144 |
| Weighted Avg | 0.99 | 0.99 | 0.99 | 144 |

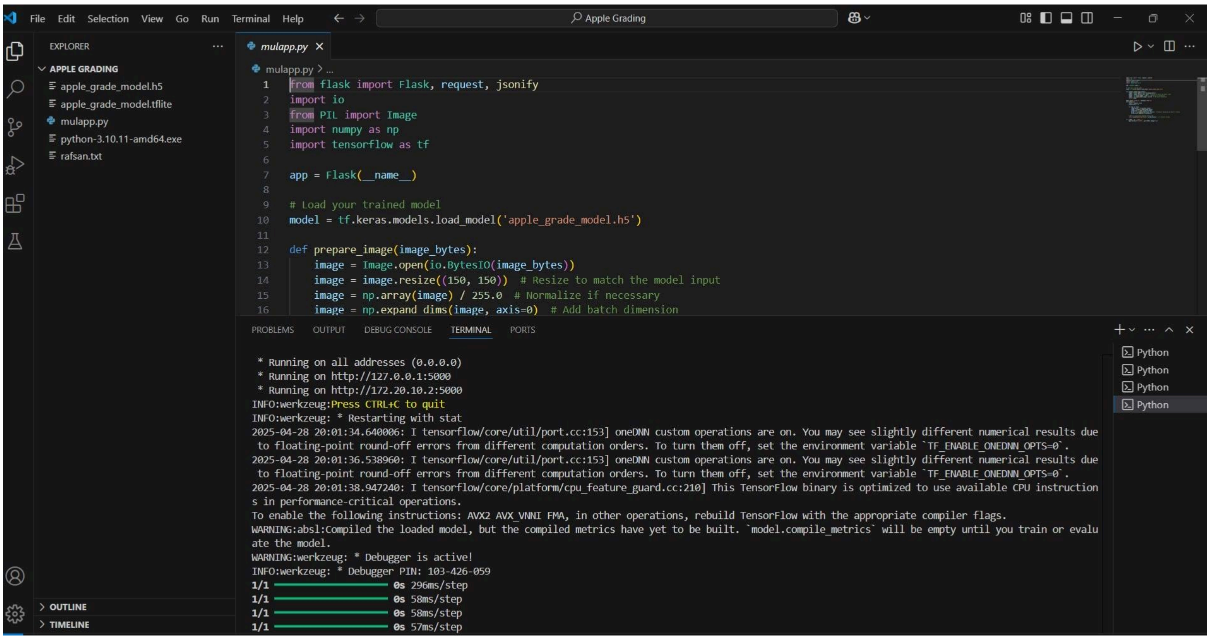
Table 8: Classification Report

### 5.3.3 Power Efficiency [CO8, CO12]

- Power Source: 7.4V 1500mAh LiPo battery
- Avg. Current Draw: 2.1A (Peak: 2.3A)
- Energy Consumption per Test Cycle: 0.012 kWh
- Runtime: ~8 hours per full charge
- Thermal Characteristics: Max internal temperature observed: 43.7°C (within safe limits)

### 5.3.4 Validation via Exhibits [CO8]

- **Visual Studio (Flask Interface Output):**



```python
from flask import Flask, request, jsonify
import io
from PIL import Image
import numpy as np
import tensorflow as tf

app = Flask(__name__)

# Load your trained model
model = tf.keras.models.load_model('apple_grade_model.h5')

def prepare_image(image_bytes):
    image = Image.open(io.BytesIO(image_bytes))
    image = image.resize((150, 150))  # Resize to match the model input
    image = np.array(image) / 255.0  # Normalize if necessary
    image = np.expand dims(image, axis=0)  # Add batch dimension
```

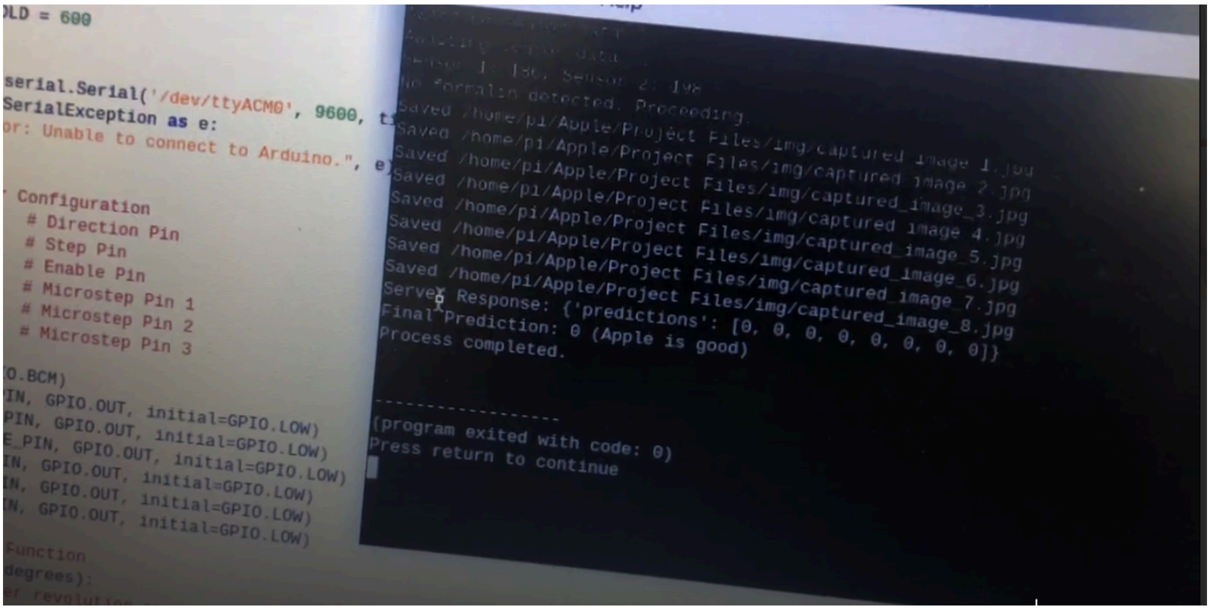
```
 * Running on all addresses (0.0.0.0)
 * Running on http://127.0.0.1:5000
 * Running on http://172.20.10.2:5000
INFO:werkzeug:Press CTRL+C to quit
INFO:werkzeug: * Restarting with stat
2025-04-28 20:01:34.640006: I tensorflow/core/util/port.cc:153] oneDNN custom operations are on. You may see slightly different numerical results due
 to floating-point round-off errors from different computation orders. To turn them off, set the environment variable `TF_ENABLE_ONEDNN_OPTS=0`.
2025-04-28 20:01:36.538960: I tensorflow/core/util/port.cc:153] oneDNN custom operations are on. You may see slightly different numerical results due
 to floating-point round-off errors from different computation orders. To turn them off, set the environment variable `TF_ENABLE_ONEDNN_OPTS=0`.
2025-04-28 20:01:38.947240: I tensorflow/core/platform/cpu_feature_guard.cc:210] This TensorFlow binary is optimized to use available CPU instruction
s in performance-critical operations.
To enable the following instructions: AVX2 AVX_VNNI FMA, in other operations, rebuild TensorFlow with the appropriate compiler flags.
WARNING:absl:Compiled the loaded model, but the compiled metrics have yet to be built. `model.compile_metrics` will be empty until you train or evalu
ate the model.
WARNING:werkzeug: * Debugger is active!
INFO:werkzeug: * Debugger PIN: 103-426-059
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 296ms/step
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 58ms/step
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 58ms/step
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 57ms/step
```

Our classification is as follows:

0 (Good) for Grade A, 1 (Worse) for Grade B and 2 (Worst) for Grade C

- **Exhibit A (Grade A Apple):** Apple was rotated 8 times with the help of stepper motor. The 8 pictures were each analyzed 8 times and all 8 were classified as 0. Thus, giving us the conclusion that the apple is Grade A (Good).

Figure 15: Grade A apple



```
LD = 600

serial.Serial('/dev/ttyACM0', 9600, t
SerialException as e:
or: Unable to connect to Arduino.", e)

 Configuration
  # Direction Pin
  # Step Pin
  # Enable Pin
  # Microstep Pin 1
  # Microstep Pin 2
  # Microstep Pin 3

O.BCM)
IN, GPIO.OUT, initial=GPIO.LOW)
PIN, GPIO.OUT, initial=GPIO.LOW)
E_PIN, GPIO.OUT, initial=GPIO.LOW)
IN, GPIO.OUT, initial=GPIO.LOW)
IN, GPIO.OUT, initial=GPIO.LOW)
N, GPIO.OUT, initial=GPIO.LOW)

Function
degrees):
```

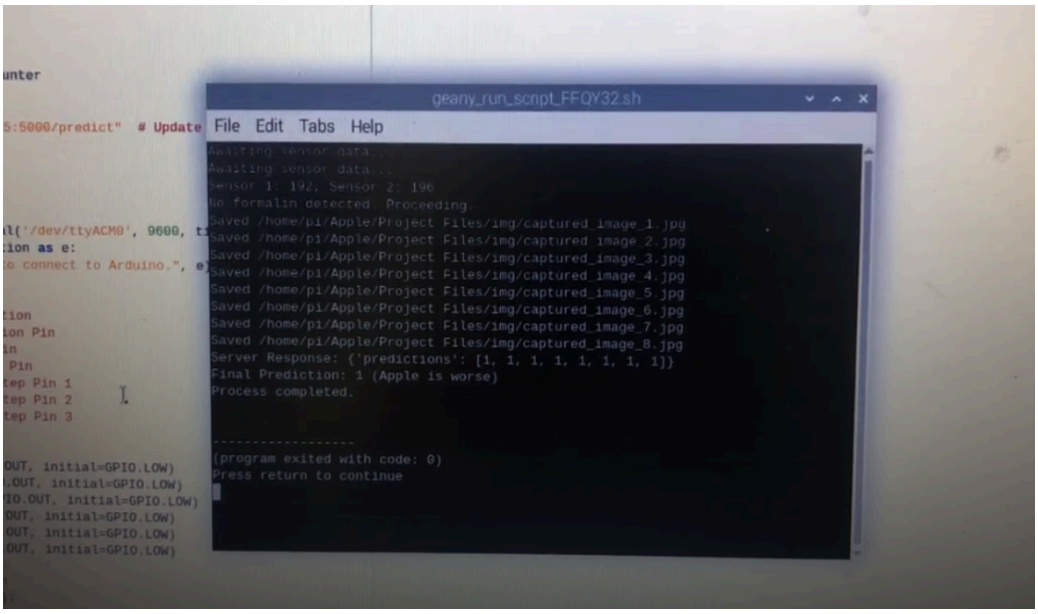
```
Sensor 1: 136, Sensor 2: 198
No formalin detected. Proceeding.
Saved /home/pi/Apple/Project Files/img/captured_image_1.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_2.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_3.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_4.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_5.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_6.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_7.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_8.jpg
Server Response: {'predictions': [0, 0, 0, 0, 0, 0, 0, 0]}
Final Prediction: 0 (Apple is good)
Process completed.


------------------
(program exited with code: 0)
Press return to continue
```

Figure 16: Output giving 0 which is for grade A

- **Exhibit B (Grade B Apple):** CNN successfully identified the minor blemishes in the eight pictures taken. This resulted in it classifying it as 1 (Grade B/worse)

Figure 17: Grade A apple



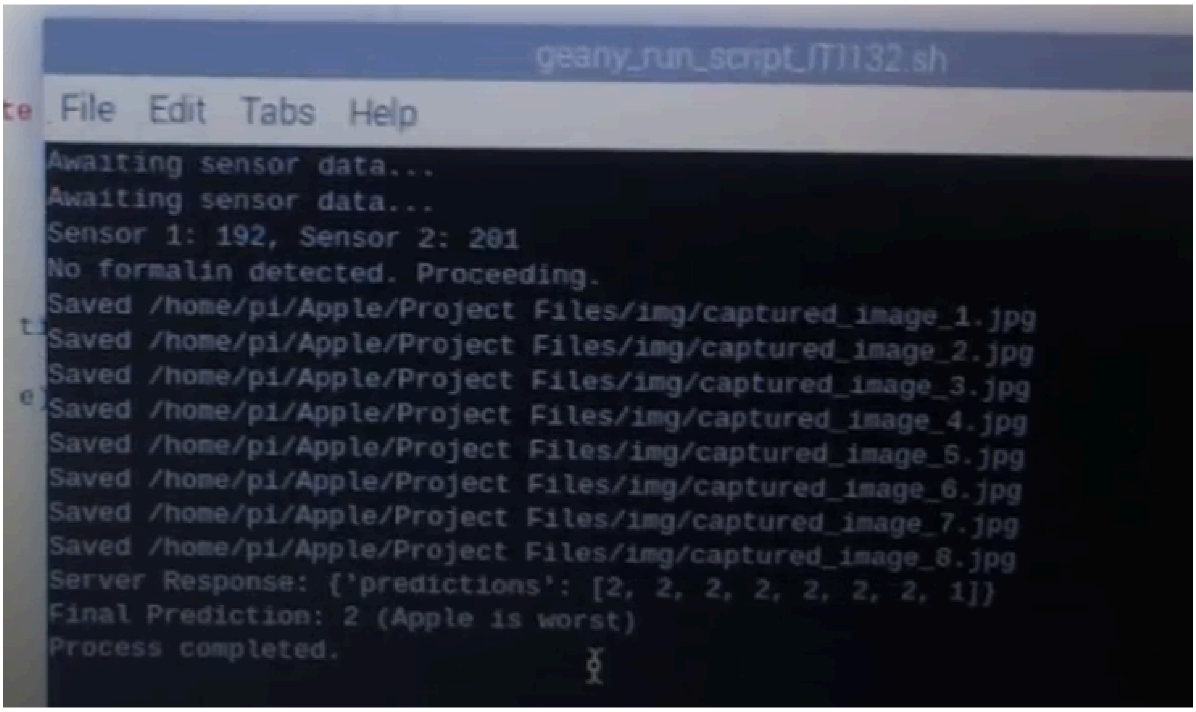
```
Awaiting sensor data...
Awaiting sensor data...
Sensor 1: 192, Sensor 2: 196
No formalin detected. Proceeding.
Saved /home/pi/Apple/Project Files/img/captured_image_1.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_2.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_3.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_4.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_5.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_6.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_7.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_8.jpg
Server Response: {'predictions': [1, 1, 1, 1, 1, 1, 1, 1]}
Final Prediction: 1 (Apple is worse)
Process completed.


------------------
(program exited with code: 0)
Press return to continue
```

Figure 18: Output giving 1 which is for grade B

- **Exhibit C (Grade C Apple):** Again each picture was classified individually. As our priority has been set as Grade C > Grade B > Grade A (i.e if even one of the images is classified as 2, then that apple is classified as Grade C), this apple got classified as Grade C even though not all eight images were graded as Grade C.

Figure 19: Grade C apple

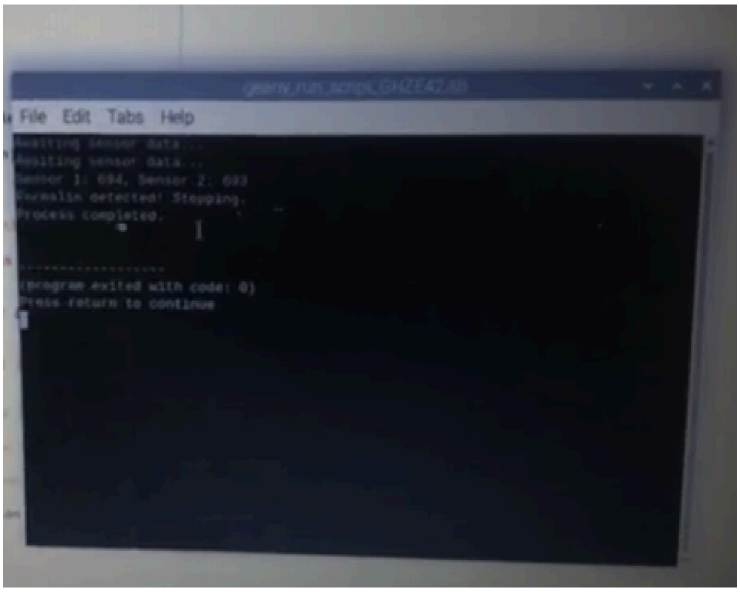


```
Awaiting sensor data...
Awaiting sensor data...
Sensor 1: 192, Sensor 2: 201
No formalin detected. Proceeding.
Saved /home/pi/Apple/Project Files/img/captured_image_1.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_2.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_3.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_4.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_5.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_6.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_7.jpg
Saved /home/pi/Apple/Project Files/img/captured_image_8.jpg
Server Response: {'predictions': [2, 2, 2, 2, 2, 2, 2, 1]}
Final Prediction: 2 (Apple is worst)
Process completed.
```

Figure 20: Output giving 2 which is for grade C

- **Exhibit D (Formalin Treated Apple):** As shown in the block diagram earlier in Chapter 2, if formalin detected then our entire process is stopped form going forward with the classification. In this scenario, formalin sensor triggered shutdown at 14s, system halted further image capture and flagged alert

Figure 21: Apple being adulterated with formalin



```
Awaiting sensor data...
Awaiting sensor data...
Sensor 1: 694, Sensor 2: 693
Formalin detected! Stopping.
Process completed.


------------------
(program exited with code: 0)
Press return to continue
```

Figure 22: Output giving Formalin detected and stopping the entire process

### 5.3.5 Limitations

- The dataset needs to be expanded for all the fruits to make it viable for the market.
- The time, especially for the detection of formalin itself needs to be improved
- Dataset might not represent the full diversity of apples we may encounter
- Borderline cases between grades creating inconsistency

### 5.3.6 Possible Improvements

Even though most of the possible improvements are mentioned in the future works sections, some minor improvements we can do to our existing prototype are:

- Custom make more sensitive sensors through manual PCB design in order to detect adulteration in micro ppm level
- Use higher resolution cameras for both dataset creation and image processing to increase the details of feature extraction and to take into consideration the smallest of bruises while grading.

### 5.3.7 Sources of uncertainty

While the sources of uncertainty in this project are minimal due to our controlled environment creation and own dataset, it does exist.

- Hues of red that are not identifiable by the CV model.

- Ambient lighting that may enter the box through the glass panel we made for viewing can in fact alter how the red appears to the camera, giving false classification.
- Battery charge depletion can lead to the motor not rotating so the same surface of the apple will be analyzed multiple times if this happens.
- If, for any reason, the intensity of the light set inside varies that may also have some effect on the classification.

### 5.3.8 Comparison with existing solutions

No solution incorporates both quality sorting and adulteration detection together, so direct comparison is not possible. However, we managed to obtain very high accuracy through our model due to an in house dataset which surpasses the accuracy of the models in the papers we looked at by 1.7%.

## 5.4 Conclusion

The final prototype demonstrates successful realization of a real-time apple classification and adulteration detection system, meeting the intended engineering design objectives. The system integrates modern AI techniques, embedded firmware, real-time data acquisition, and a multi-sensor architecture. Its robustness, modularity, and low power consumption make it suitable for deployment in low-infrastructure rural settings. It meets the complex engineering design criteria outlined in CO8 and effectively leverages tools and methodologies aligned with CO9 and CO15.

# Chapter 6: Impact Analysis and Project Sustainability. [CO3, CO4]

## 6.1 Introduction

Beyond its technical achievements, this chapter addresses the broader implications of the formalin detection and apple sorting system across socio-economic, environmental, and sustainability dimensions. The project contributes to several UN Sustainable Development Goals (SDGs), notably:

- **SDG 3:** Ensure healthy lives and promote well-being
- **SDG 9:** Build resilient infrastructure, promote sustainable industrialisation
- **SDG 12:** Ensure sustainable consumption and production patterns

The proposed system demonstrates transformative potential across social, environmental, and economic dimensions. By addressing the pervasive issue of formalin adulteration in perishable goods, the project directly contributes to Sustainable Development Goal 3 (Good Health and Well-Being), reducing risks of chronic illnesses linked to formaldehyde exposure, such as liver cancer and respiratory disorders. Simultaneously, its focus on fair quality-based pricing empowers small-scale farmers, advancing SDG 12 (Responsible Consumption and Production) by fostering ethical agricultural practices and reducing post-harvest waste.

## 6.2 Societal and Economic Impact [CO3]

*Public Health Protection:* Formaldehyde is a known carcinogen and causes long-term health problems. By detecting and eliminating adulterated apples early in the supply chain, the device reduces exposure and prevents potential health crises. Its integration at wholesale and retail levels will significantly reduce adulteration cases.

*Farmer Empowerment:* Automated sorting provides transparent grading and incentivizes farmers to improve produce quality. This can translate to increased income through quality-based pricing structures and reduces exploitation by intermediaries.

*Trust in Domestic Produce:* By ensuring safety and traceability, the system restores consumer confidence in local markets. This reduces the demand for imported fruits, positively affecting the national agricultural economy.

*Technological Awareness:* The project promotes educational reform by demonstrating how embedded AI systems can improve agriculture. Public exhibitions and educational use can further increase food safety awareness.

### 6.3 Environmental and Operational Sustainability [CO4]

*Low Energy and Off-Grid Operation:* With a power requirement of just 0.012 kWh/test, the system consumes 25% less energy than most commercial testers. Its compatibility with solar-charging makes it viable in remote rural settings without reliable electricity.

*Sustainable Materials:* PLA 3D-printed components ensure biodegradability. Sensors used have a life cycle of over 5 years, and minimal electronic waste is generated due to modular design.

*Open Design and Scalability:* The system is built on open-source hardware and software, encouraging customization and adoption across regions. With a bill of materials costing BDT 29,000, the design is affordable and feasible for small agro-businesses and local cooperatives.

*Scalable Upgrades:* Future improvements may include:

- Hyperspectral sensors for more accurate classification
- Wireless IoT data transmission
- Blockchain integration for end-to-end food traceability

### 6.4 Conclusion

The project successfully transcends traditional engineering domains to deliver a solution that is socio-economically relevant and environmentally conscious. Its low-cost, accurate, and portable nature makes it ideal for grassroots deployment in food safety monitoring. By aligning with sustainability frameworks and ethical standards, the solution stands as a replicable model for other regions and food types, underscoring the power of engineering in public health advocacy and community empowerment.

# Chapter 7: Engineering Project Management. [CO11, CO14]

## 7.1 Introduction

In the rapidly growing and changing domain of engineering, it is essential for engineers to learn advanced technology along with good project management skills. The uncertainty of whether the project can be done on time and excessive costs that are not controllable happen due to system management lacking the needed focus. The effectiveness of project management means taking care of problems that occur unexpectedly, thereby maintaining project goals and achieving schedule targets. A project achieves success only with three main factors, such as: correctly scoping work tasks under time constraints; creating strong partnerships between teams and stakeholders; and preparing contingency plans for emergencies. Project management applications prove efficient in company process management because they enable teams to track their progress and foresee potential obstacles. The assigned team tasks receive periodic updates through which issue detection is possible and project progress is further maintained. Teams demonstrate their capacity to be long-term sustainable and introduce innovations by adjusting to new circumstances that arise through ongoing project management.

## 7.2 Define, plan and manage engineering project

Table 9 : EEE499P Project Plan

| ***Task*** | ***Start Date*** | ***End Date*** | ***Duration*** |
|---|---|---|---|
| Discussion on topic selection | June 10 | June 18 | 9 |
| Topic finalization | June 19 | June 26 | 8 |
| Literature review | June 27 | June 30 | 4 |
| Preparation of concept note | July 1 | July 5 | 5 |
| Progress presentation | July 6 | July 8 | 3 |
| Dimension analysis | July 9 | July 10 | 2 |
| Multiple design approach | July 11 | July 14 | 4 |
| Optimal solution finding | July 15 | July 22 | 8 |
| Budget planning | July 23 | August 1 | 10 |
| Ethical and safety considerations | September 3 | September 6 | 4 |
| Project proposal draft | September 8 | September 14 | 6 |
| Final presentation | September 17 | September 19 | 3 |
| Project proposal report | September 22 | September 26 | 5 |

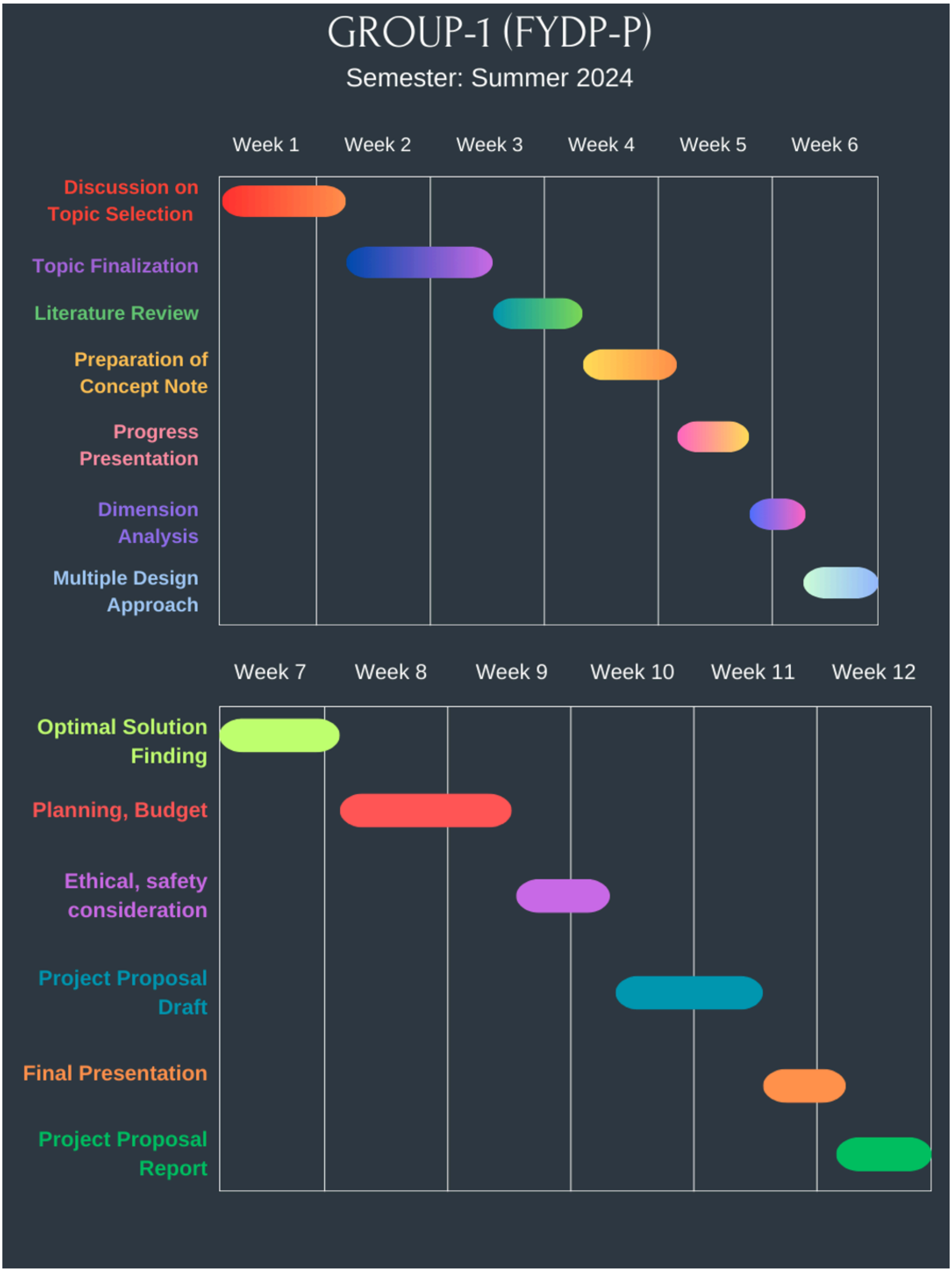


Fig 23: Gantt Chart for FYDP-P

Table 10: EEE499D Project Plan

| ***Task*** | ***Start Date*** | ***End Date*** | ***Duration*** |
|---|---|---|---|
| Preparation of design process | October 14 | October 23 | 10 |
| Alternative design analysis | October 26 | October 31 | 6 |
| Analyze solutions with modern tools | November 3 | November 7 | 5 |
| Optimal solution analysis | November 11 | November 14 | 4 |
| Optimal solution finding | November 17 | November 19 | 3 |
| Progress presentation | November 22 | November 23 | 2 |
| Design and validation | November 25 | November 28 | 4 |
| Optimal solution implementation | December 1 | December 7 | 7 |
| Impact and sustainability check | December 10 | December 14 | 5 |
| Algorithm development | December 17 | December 24 | 8 |
| Project report draft | December 27 | January 1 | 6 |
| Final presentation | January 4 | January 5 | 2 |
| Project report submission | January 9 | January 14 | 5 |

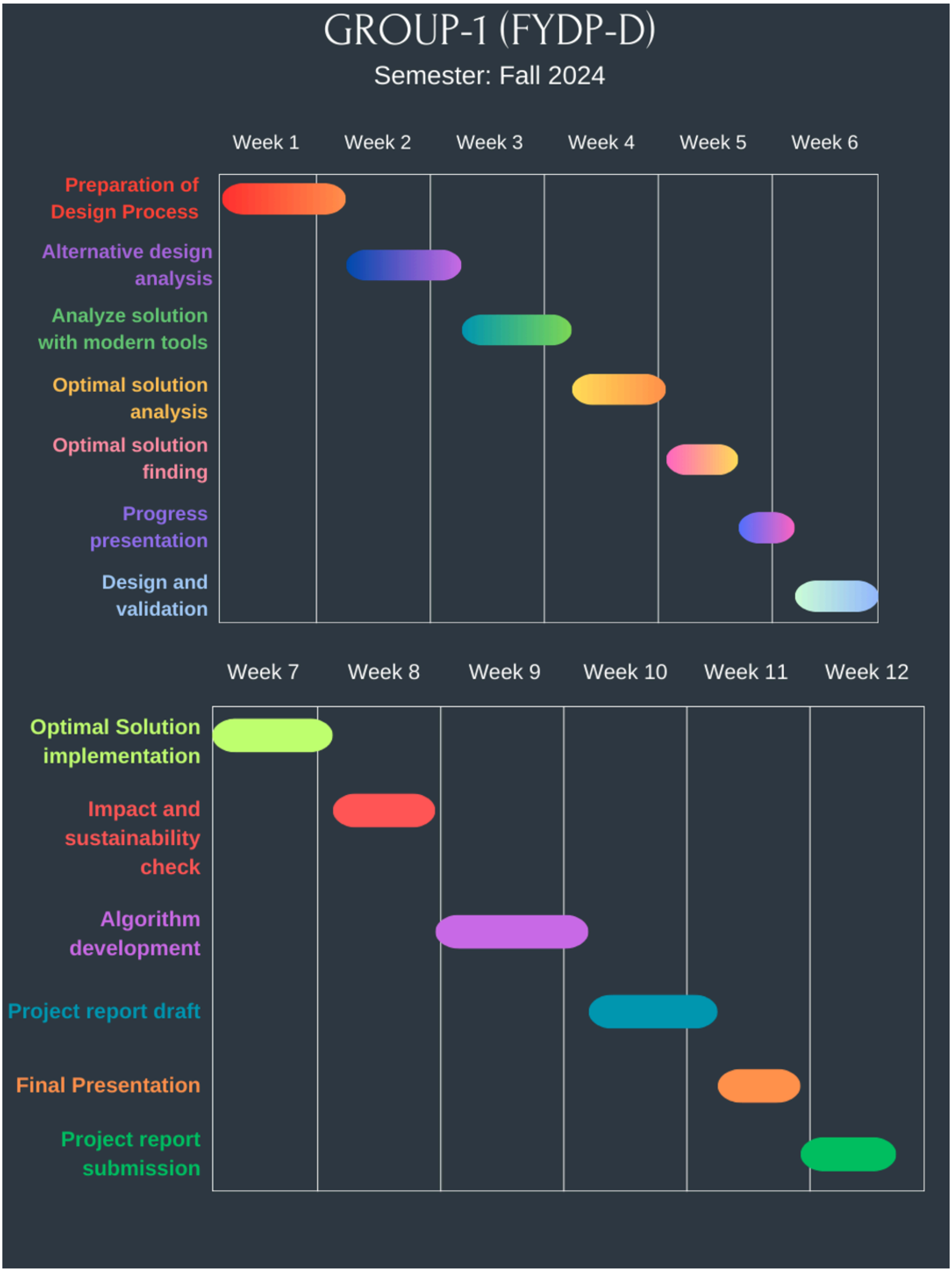


Fig 24: Gantt Chart for FYDP-D

Table 11: EEE499C Project Plan

| ***Task*** | ***Start Date*** | ***End Date*** | ***Duration*** |
|---|---|---|---|
| Implementation of selected design approach | February 15 | February 21 | 7 |
| Testing and evaluation | February 24 | March 4 | 9 |
| Data collection | March 7 | March 12 | 6 |
| Data analysis | March 15 | March 18 | 4 |
| Progress presentation | March 21 | March 23 | 3 |
| Result analysis | March 26 | March 29 | 4 |
| Documentation | April 4 | April 8 | 5 |
| Algorithm development | April 11 | April 21 | 11 |
| Project report draft | April 24 | May 6 | 13 |
| Final presentation | May 7 | May 11 | 5 |
| Project report submission | May 12 | May 15 | 4 |

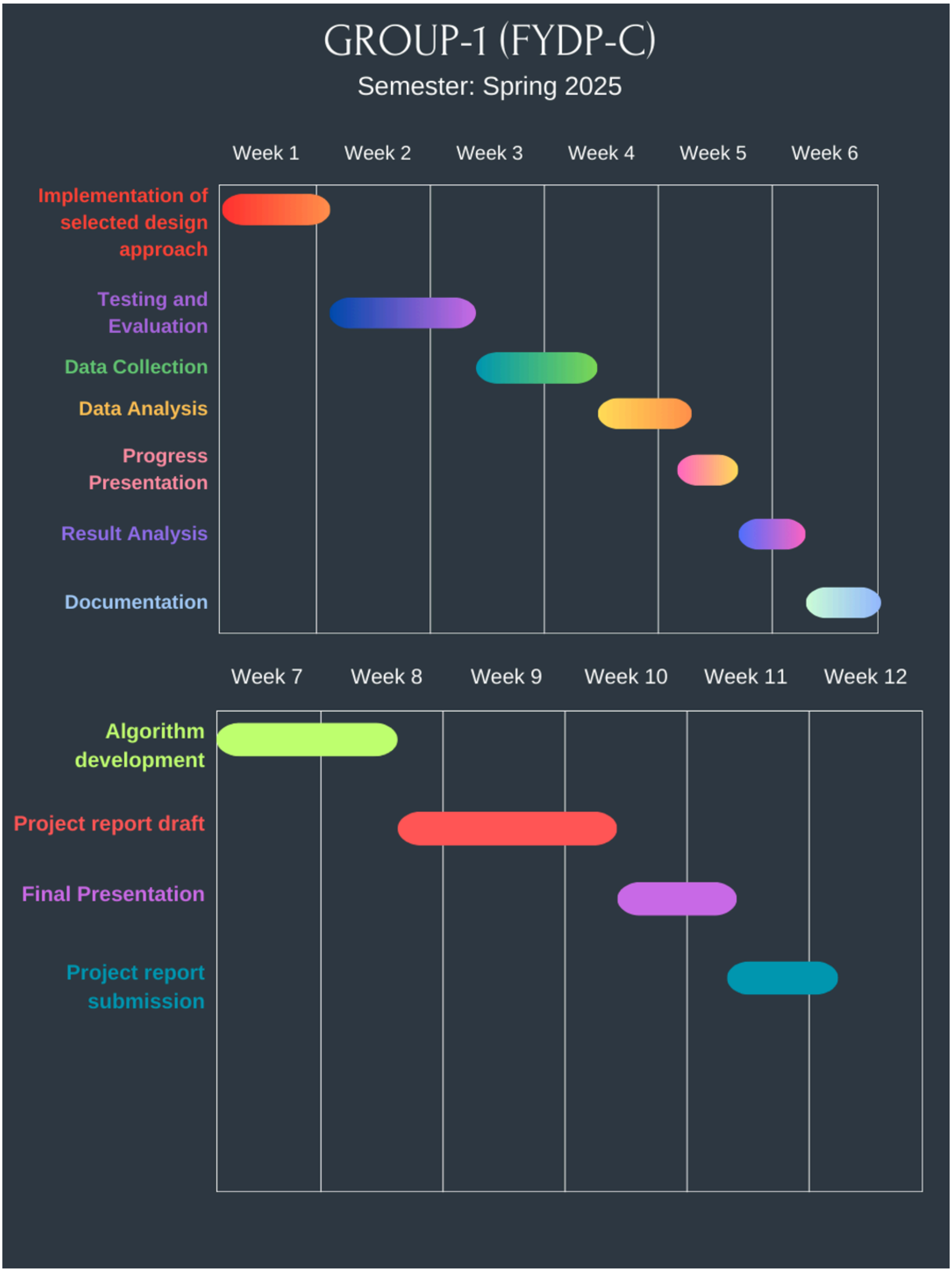


Fig 25: Gantt Chart for FYDP-C

### 7.3 Evaluate project progress

The system has been subjected to a series of rigorous tests over various stages in order to verify its reliability and operational efficiency. For instance, the individual tests that were performed included an evaluation of the operational performance of hardware components which comprised the MS1100 formaldehyde gas sensor and the Raspberry Pi camera module as well as the stepper motor-driven rotating platform. Testing under standardized conditions with formalin solutions of various concentrations confirmed the gas sensor's ability to detect correctly, and the camera module performed quality checks in different lighting environments. Tests took place to determine whether the stepper motor functioned properly in conjunction with the rotating platform and that they were well controlled for taking apple imagery from different angles. The testing phase verified the operation of the formalin detection sensor in cooperation with the image processing system creating a common link between the two devices. The image classification system was tested with a large assortment of apple samples to evaluate if the performance in quality sorting met the expectations. The camera and the rotating platform were synchronized in a test exercise to eliminate motion blur in the process of testing. The final stage of the evaluation was performed by carrying out a complete system test in a real-world scenario. The system dealt with both contaminated apples, those with used formalin and not, during the detection checks, thus, system reliability and operation speed were checked as well. The evaluation of the system performance focused on the issues of the false positive errors, the false negative errors, and the classification accuracy rate. The detection algorithms were given necessary modifications to improve performance, while the sensor response delay was kept minimal as an optimal balance between speed and accuracy results.

The correct working of the formalin detection and apple sorting technology can not be imagined without the consistent intertwining of hardware and software components, which in turn carry their risks affecting the system performance and reliability. Fire hazards as a consequence of incorrect wiring or ruinous plugs and power outages represent considerable risks by way of such a system breakdown or data error. The system acts against electrical tribulations by the pursuit of properly insulated wiring, scheduled inspection, and grounding system installation. The problem was solved by sensor calibration and algorithm adjustments together, which were unattached at a time. Fluctuations in lighting quality impact the classifier by making image database errors. This problem was solved by a controlled imaging system with steady lighting. Meanwhile, the detection algorithms have been finished through comprehensive testing along with dataset refinement, which makes it possible to. The classification was accurate. The proactive risk management has resulted in system optimization, which in turn provides stable performance in real-world scenarios.

Table 12: Risk Response Matrix

| ***Risk Event*** | ***Potential Impact*** | ***Management Procedure*** | ***Contingency Plan*** |
|---|---|---|---|
| Hardware component failure | Failure of sensor or camera or stepper motor units would stop formalin detection and apple sorting operations resulting in improper classification while also causing the system to shut down. | Equipment reliability spans time-extended spans with routine performance checks and preventive maintenance that depends on industrial-grade components. | A quantity of critical spare parts should be kept available for substituting failed components to provide continuous system operation. |
| Sensor calibration drift | Repeated exposure of the formalin sensor to its surroundings can diminish its sensitivity which results in false detection of contaminants thus raising the chance of approving dangerous apples. | The sensor baseline can be reset through scheduled calibration procedures with known formalin concentrations while self-adjusting software takes care of calibration drift. | The system needs an additional formalin detector using chemical confirmation tests which confirms unclear sensor results. |
| Software bugs in the classification system | Incorrect algorithm execution during machine learning produces both plentiful false signals and faulty findings which affects the combined reliability of formalin detection as well as apple grading quality. | A complete dataset validation process should be performed before training the classification model with additional samples from various sources to enhance performance accuracy. | The system should have a backup classification protocol that functions by rule-based statements to assume control if machine learning operations fail to preserve operational capacity. |
| Lighting inconsistencies affecting image processing | Changes in ambient illumination levels affect image quality which consequently leads to mistaken classification of apple quality. | A dedicated imaging chamber with an enclosed design and uniform LED lighting system should be used for maintaining consistent brightness and reducing shadow formation and reflection issues. | Design an image-processing system that automatically changes lighting characteristics according to present environmental conditions. |

| | | | |
|---|---|---|---|
| Power failure or voltage instability | Operation downtime alongside corrupted data would become possible when the power supply abruptly interrupts the system. | The system should use voltage stabilizers together with battery backup mechanisms to sustain continuous operation. Testing the backup power supply on a regular basis should verify its operational readiness. | The utilization of Uninterruptible Power Supply(UPS) systems should be coupled with automatic information-saving protocols to back up mission-critical data when power interruptions occur. |
| Environmental contamination affecting sensor readings | Sensor misreadings for formalin detection will occur when dust, moisture or foreign matter affects its accuracy. | Sensor protection systems along with recurring component cleansing operate to stop contamination accumulation. | The implementation of multiple sensors allows comparisons between their results to detect and eliminate false data that comes from environmental contamination. |

System performance enhancement requires multiple vital upgrades that focus on improving accuracy alongside efficiency and user-friendliness. The formalin detection algorithm needs enhancement through the expansion of training dataset contents with different formalin concentration levels. By refining the detection process the system obtains better precision combined with lowered mistakes of classification. The team needs to work simultaneously to enhance response time performance by optimizing real-time data flow processing simultaneously with hardware component communication systems. The improvement of data processing operations through pipeline optimization will let detection and classification happen more rapidly. The system needs enhanced scalability through modular design to make it workable in industrial complexes. A new interface system is being developed because it will allow non-expert users to use the system easily. Visual sensor calibration techniques are now being developed to give hardware systems accurate readings independently of manual intervention. The system development incorporates enhancements for battery performance alongside power efficiency improvements to operate effectively when faced with unreliable electrical power supplies. The combination of these developments will establish a dependable and precise system that provides easy use for various industrial and agricultural needs.

## 7.4 Conclusion

Project management controls the success of projects because it establishes an organizational structure that combines directional supervision throughout the entire project development.
Project management secures the success of projects by establishing an organizational framework that ensures the directional supervision of all project activities. The mixture of undefined management practices and non-established rules leads to insufficient consistency in project goal achievement, thereby wasting project resources and prolonging project implementation durations. Tentative changes of happening want, and planning mostly handle social problems and technical issues, necessitating shifts of these catechisms. Besides the

health risks, various factors such as the economy and political situations can also affect the project outcomes. Every project should have, among others, contingency plans for the occurrences of unknown events that might cause changes in the planned activity and thus necessitate extra measures. The reason for being fully accountable is the comprehensive described records about the work carried out and the proofs involving numbers to every statement made in each step of the project. With zero tolerance for waste, project management covers both the efficiency of daily operations and the advantages of team collaboration and successful outcomes from the thorough planning and clear-cut strategies applied and the continuous monitoring done. As the FYDP teams have flexible mechanisms along with the far-sighted problem-solving techniques, they efficiently handle the issues that arise and accomplish the set goals thus creating the sound preconditions for the business to evolve.

# Chapter 8: Economical Analysis. [CO12]

## 8.1 Introduction

The analysis of investment research benefits follows the economic assessment methods, together with cost analysis. The approach through which companies examine and project market behaviors differently has been facilitated by such analysis which uses the advantage of studying the influence on consumers and competitors in addition to the business model. A company's economic analysis is a crucial means of acquiring necessary information for decision-making related to the cost and profit aspects as it relates to production and distribution costs, marketing costs, and possible returns from investment in a business. By means of this analytical model, companies are not only in a position to make proper decisions about the launching of new products and pricing decisions but also about the promotional and distribution channels but also, unfold the possible risk attached to it in terms of market development. The cost-benefit ratio from economic logic is brought out in the overall terms of the economic value of actions after the assessment of expenses in total and the efficiency of the actions in that order. Such evaluations are a great advantage to project developers in their efforts to design sustainable finances, save costs, and optimize their financial operations through taxation measures. Successful project handling and assessment, together with strategic planning, demand both economic and financial evaluations.

## 8.2 Economic analysis

The combination of hybrid sensor technology and CNN-based system for formalin detection and apple classification costs less than titration and chromatography techniques because it eliminates the need for complex laboratory equipment together with expensive staffing and extended processing delays. The current conventional detection systems prove too expensive to serve the needs of widespread market testing alongside agricultural production facilities and home use. The proposed system, with its MS1100 gas sensor and CNN-based image classification, delivers affordable automation and scalability and achieves cost-efficient detection operations with accepted accuracy levels. The system eliminates dependence on expensive spectroscopy-based methods to provide instant on-site testing, which needs only minimal upkeep costs. Through this technology, farmers and vendors achieve three benefits: apple quality grading (A, B, C) classification while maintaining transparent pricing, increased market competition, and enhanced consumer trust in product safety. The system helps ensure regulatory compliance and decreases healthcare costs because it mitigates food contamination through formalin adulteration. Food supply chain operators should consider implementing the device because of its low cost, user-friendly design, and expandable capability, allowing for widespread use throughout food supply chain operations, resulting in better food safety regulations and sustainable economic practices. The financial feasibility of this solution stems from its combination of capital cost at implementation and long-term benefits that include economic efficiencies, product quality improvements, and market performance enhancements within the agricultural and food distribution sectors.

### 8.3 Cost-benefit analysis

Stakeholders use cost-benefit analysis (CBA) as an essential instrument that determines whether anticipated design benefits exceed related project expenses. CBA contributes to making the right choice of the greenest engineering project solutions by maintaining the financial and functional viability of the project design. The main purpose is to lower the total costs and preserve the peak efficiency of the operation and the long lifespan of the system together. Elements of the project and their chosen methods, in addition to the aforementioned, have to take the technical standards and the budget feasibility seriously in order to achieve a situation of high performance at an acceptable cost.

The identification of the best implementation approach for formalin adulteration detection and apple sorting based on quality depends on CBA in this project. An effective detection system that also performs quality sorting of apples specifically needs to exist due to widespread formalin adulteration because it ensures consumer health protection and enhances food quality control standards. The main issue emerges from striking a proper equilibrium between system precision and cost-efficiency alongside deployment practicality. The research analysis includes two design approach methods that will be evaluated:

1. The first design incorporates formalin detection through MS1100 gas sensors combined with image processing for quality sorting operations.

2. The second design method uses spectroscopy instruments (UV-Vis & NIRS) for formalin detection, followed by colorimetric sorting to classify apples.

The comparison of these approach designs will reveal which solution provides maximum scalability, cost-effectiveness, and performance quality.

**Design Approach 1: Sensor-Based Formalin Detection and Image Processing**

| *Component* | *Price (BDT)* | *Benefits* | *Drawbacks* |
|---|---|---|---|
| MS1100 Gas Sensor | 4*<br>(1200) | This device performs exceedingly accurate formaldehyde vapor detection by means of its high sensitivity. The detection system integrates easily since it operates portably with small dimensions. The system can detect hazards right as they occur in real-time. | The device needs periodic calibration procedures to function accurately. Failure to properly shield the device can result in environmental gas disruptions which generate false results. |
| Raspberry Pi 4 | 10,000 | The device possesses strong computational abilities that lead to the straightforward operation of machine learning (ML) algorithms to classify apples. The system enables real-time data logging and remote monitoring because of integrated IoT capabilities. The system has built-in scalability which enables it to accept further sensor units when expansion takes place. | The microcontroller utilizes more power than basic microcontrollers. This device costs more than the standard options including the Arduino platform. The device becomes hazardous to use when it operates for extended periods without access to cooling mechanisms. |
| Raspberry Pi Camera (8MP) | 4,637 | The device takes sharp detailed images that result in exact apple identification. The system operates real-time image processing through convolutional neural networks (CNNs). The device stays portable because of its miniaturized design and lightweight. | Performance depends on lighting conditions. Deteriorated visibility in the environment causes devices to confuse substances during screening. Complete visual monitoring requires multiple camera systems since cameras have restricted viewing angles. |
| Stepper Motor | 1,100 | The device enables programmed 360-degree rotational control of apples for obtaining views from every direction. The system delivers precise positioning to | Using the design requires the attachment of an extra motor driver circuit to manage device movement. Unguarded vision systems must undergo normal upkeep |

| | | | |
|---|---|---|---|
| | | ensure standard image collection. | to minimize structural damage. |
| Motor Driver | 850 | The stepper motor obtains accurate directional control together with speed control abilities. The system prevents strong power drain which leads to stable device operation. | Extra costs appear when integrating this component into the system framework. Thorough cabling connections and computer code writing become essential for achieving synchronization between system components. |
| Power Supply (Lipo Battery 1500mAh) | 1,300 | Compact and rechargeable, ensuring portable operation. The system possesses adequate energy levels which enable the operation of every device. | The system needs constant recharging for continuous operation because its battery has limited capacity. The performance of batteries faces decreasing functionality because of natural aging. |
| Display Unit (3.5” LCD) | 2,800 | The device displays an immediate visual representation of formalin test results and classifies apple quality simultaneously. Users can interact easily through the system without requiring an external monitor for operation. | Increases the overall cost of the system. Remote monitoring systems will make this component unnecessary for monitoring purposes. |
| Miscellaneous (Wires, 3D Printing, Mounts, Connectors) | 700 | The proper wiring connections and structural stability of the device are ensured by this component. Additionally the 3D-printed enclosure guards sensors from environmental interference. | The prototype exhibits increased costs because durability and protection demand this element. |

***Total Estimated Cost for Design Approach 1: 26,187 BDT***

**Design Approach 2: Spectroscopy-Based Detection with Colorimetry**

| ***Component*** | ***Price (BDT)*** | ***Benefits*** | ***Drawbacks*** |
|---|---|---|---|
| Near-Infrared (NIRS) Sensor | 3*<br>(4,692) | The system implements formalin detection without touching the food items. High sensitivity to molecular absorption changes. Long lifespan with minimal wear and tear. | Expensive compared to gas sensors. The monitoring process needs difficult calibration procedures between different kinds of apple varieties. |
| UV-Vis Spectroscopy Sensor | 3*<br>(1,700) | The device uses spectroscopic methods to detect formalin fraud precisely. Works effectively across a broad range of chemical compounds. | The sensor needs controlled lighting conditions because it shows high sensitivity to environmental light. The response of light sensors operates more slowly than gas detection capabilities. |
| TCS3200 Colorimeter | 515 | The system provides exact detection of apple colors for sorting purposes. The device provides precise grading results through spectral comparisons. | The existence of color differences does not necessarily correlate to apple freshness. The system reacts strongly to changes in illumination and camera positioning. |
| Raspberry Pi 4 | 10,000 | Spectral data processing and classification operations need this program as a requirement. This system utilizes AI technology for conducting authentic real-time detection and sorting quality assessments. | High processing demand due to data-heavy spectroscopy calculations. Increases power consumption. |
| Power Supply (Lipo Battery) | 1,300 | Same as Design Approach 1. Supports portability. | Sensor replacements become necessary during their limited operational period. |

| | | | |
|---|---|---|---|
| Display Unit (3.5" LCD) | 3,800 | The system enables real-time observation of both spectral data and results of classification. | Apple freshness evaluation through real-time monitoring will not need this device since testers can access results on their mobile screen. |
| Miscellaneous (Wires, Mounts, Connectors) | 250 | The system requires this element for proper structural design and electronic functionality. | The device requires extra expense while being necessary to achieve reliable performance. |

***Total Estimated Cost for Design Approach 2: 35,041 BDT***

Design Approach 1 proves more economical because its implementation costs 8,854 BDT less than the spectroscopy-based approach that requires expensive spectral sensors. The MS1100 sensor in Design Approach 1 detects formalin with complete accuracy but Design Approach 2 achieves detection accuracy of only 73.8% and requires frequent calibration measures. Design Approach 2 stands apart from other methods when sorting quality because its colorimetric analysis provides 77% accuracy, while the sensor-based method reaches only 60% (due to a poorly distributed dataset while training the model). To help improve the condition for Design Approach 1,an equally balanced dataset was created from scratch.As a result,the accuracy from Design Approach 1 goes from 60% to 99%.The implementation of Design Approach 1 proves superior due to its practical adaptability through pre-trained image processing models. On the other hand, manufacturing and deploying Design Approach 2 becomes complex because of extensive spectral sensor calibration requirements. The approaches have equal energy requirements as they operate using a 7.4V Lipo battery, so power consumption becomes a neutral aspect.

The total financial output of 26,187 BDT enables a lower-cost solution that detects formalin at 100% accuracy required for food security purposes. Better quality sorting precision (99%) in Design Aoproach 1 vs (77%) in Design Approach 2. Hence, Design Approach 1 (Sensor-Based Formalin Detection with Image Processing) demonstrates the best selection according to the evaluation criteria of cost, accuracy, scalability, and implementation ease.

### 8.4 Evaluate economic and financial aspects

Economic and financial feasibility forms a fundamental base for maintaining sustainable long-term success and practical implementation of this project. A formalin detection system built with sensors provides cost efficiency in operation relative to traditional spectroscopy systems. The system delivers affordable detection capabilities combined with automation, which makes it suitable for widespread adoption by food-related businesses and regulatory organizations. The system achieves affordability through its easy manufacturing and reduced initial expenses, which enables extensive implementation capabilities across various environments. The rising market need for food safety solutions demonstrates promising financial opportunities, given that food suppliers and regulatory agencies, together with consumers, all value products unmolested by adulteration.

Table 13: Bill of Materials Design Approach 1

| ***Component*** | ***Quantity*** | ***Unit Cost (BDT)*** | ***Total Cost (BDT)*** |
|---|---|---|---|
| Gas Sensors (CJMCU-1100 MS1100) | 2 | 1200 | 2400 |
| Camera (Webcam) | 1 | 980 | 980 |
| Motor (Nema 17 stepper motor + motor driver + motor mount) | 1 + 1 + 1 | 1,100 + 850 + 334 | 2284 |
| Microcontroller (Raspberry Pi 4 + Arduino Nano) | 1 + 1 | 10,000 + 385 | 10,385 |
| Power Supply (Lipo Battery 1500mAh 7.4V 2S) | 1 | 1,300 | 1,300 |
| User Interface (3.5-inch Raspberry Pi Display) | 1 | 2,800 | 2,800 |
| Miscellaneous (3D Printing, Wires, Breadboard, LEDs, etc.) | - | 700 | 700 |
| **Total Budget** | **-** | **-** | **20,849 BDT** |

| | |
|---|---|
| Total component Price | 20,849 |
| Prototype Cost | 2,300 |
| Testing Cost | 2,100 |
| Delivery Cost | 1,300 |
| Emergency Cost | 2,500 |
| **Total Price** | **29,049** |

The cost-effective solution using technology shows promise to revolutionize food quality control because it identifies formalin-contaminated apples at reasonable prices. To optimize food quality control together with public health safety and sustainable agriculture the project needs to maintain its cost-effectiveness alongside scalability and simple integration into present food supply networks.

### 8.5 Conclusion

Project evaluation along with improvement for good future performance requires both economic and financial analyses. Economic analysis guarantees sustainability while financial analysis provides the information necessary for the allocation of resources, determination of optimal costs, and identification of potential scaling opportunities. The sustainability of a system for the long term is not determined by performance and productivity only but also by other factors. The system's prosperity and the consequent ability to adapt to changes are conditioned by the project's success and the external market, legislation, and technological changes. The collaborative involvement of food safety authorities with the agricultural stakeholders can enhance the market and public health stand of the system through the dual effect of their functioning.

# Chapter 9: Ethics and Professional Responsibilities CO13, CO2

## 9.1 Introduction

Engineering projects are obliged to respect ethical standards, be they moral principles, legal rules, or social norms. Engineers are professionals who should adequately handle their obligations through deeds that intersperse technical skills with the spirit of integrity for the sake of public welfare. Engineers' ethics mainly come from professional stakes in healthcare, infrastructure, and environmental sustainability, where their decisions are paramount. Operational units of engineering must deal with ethical dilemmas in upholding professional standards for two main reasons, which are customers' trust and sustainable growth with security. Engineers need to mix innovation with responsibility to ascertain public safety risks through environmental impact assessment and sustainable development capabilities. Ethics are the main foundation of the viability of a project as ethical elements amplify economic performance, and environmental sustainability in addition to social well-being. The lack of ethics in engineering projects can expose them to potential serious dangers, which may lead to safety issues, non-compliance with regulations, and a fall in their professional image. With professional responsibility and ethical principles working in tandem, engineering practice becomes a framework for building decision-making skills that take into account the needs of the community and the requirements of the industry. Engineers, who put ethics into their work practices, can progress and at the same time ensure integrity, accountability, and community welfare.

## 9.2 Identify ethical issues and professional responsibility

Contaminated fruits such as apples along with the quality-based sorting of apples are the major tasks that concern the detection of formalin in apples. The scheme is meant to deal with the problem of food adulteration as it ensures the procedure of engineering design, development, and implementation to be followed through professional and ethical principles. Thus, the ethical issues of concern in addition to the responsibilities that are a part of the project are the following:

### A) Food Safety and Public Health Responsibility

The detection of formalin with high precision is crucial to ensuring consumer safety because the project is directly related to their health. The presence of false positive readings from the system in such a case could definitely ruin the vendor's reputation, but on the other hand, the false negative results have a more serious problem as they will lead to the distribution of unwholesome apples to the public. The formalin detection system must undergo a series of quality control tests to provide reliable, and reproducible results.

### B) Responsible Use of ML in Food Quality Assessment

With the combination of Machine Learning and the computer vision approach, it is possible to sort, and tag different grades to apples based on the ripeness. The pricing and classification systems may not be able to function properly as a result of the implementation of flawed models that can cause unacceptable variations. The dataset needs to be diversified correctly with different apple types represented under various conditions to overcome this challenge. The right and just functioning of the ML model is reliant on regular updates and training sessions.

### C) Prevention of Chemical Exposure Risks

Formalin is a chemical that poses unique medical risks to people which come in respiratory problems, as well as irritation and chronic diseases. The personnel who are directly dealing with formalin samples require adhering to the specific safety protocols, which are a combination of wearing protective equipment, the upkeep of a working area, and proper waste disposal methods to avert health and environmental repercussions from the chemical.

### D) Data Privacy and Ethical Use of Information

The initiation of the software needs the data to be accumulated for food safety followed by the systematic procedure that is to be followed. The ethical issues come when the data that is sensitive such as the supplier's details and the formalin test results are wrongly used or handled. In general, the team should implement data privacy protecting so strongly that the collected data is protected from any unauthorized use or exploitation while the specific purpose-focused data utilization is guaranteed.

### E) Fairness in Agricultural Trade

The pricing and market worth of apples is influenced by the classification of apples as per the classification system. The only way to remedy the situation is for agricultural production to be assessed correctly so that growers are compensated only with fair market rates and the middlemen and market biases do not take advantage of the farmers. The system must ensure openness, and this will enable all parties involved to verify outcomes and also guarantee that ethical trade practices are observed.

## 9.3 Apply ethical issues and professional responsibility

Professional accountability, paired with ethical principles, forms the basis for engineers to follow when building projects since they achieve compliance and create confidence with the public while generating enduring results. The formalin detection, along with the apple classification system, requires the implementation of optimal industry practices to solve existing ethical problems before they occur. Ethical system execution methods exist in multiple combinations:

### A) Smart Error Management for Enhanced Public Safety

The public health system demands dual verification methods that require computer models to perform chemical strip verification testing after generating their initial outcomes. The assessment tool generates confidence score indicators to notify users about potentially incorrect results thus prompting users toward extra verification protocols. The platform would enable swift incident response by informing regulatory agencies about contamination spots early enough to prevent bigger areas from facing health risks.

### B) Transparent and Adaptive Learning to Prevent Bias

Continuous learning frameworks need implementation because they stop biases from modifying model classification decisions. Federated learning updates the system by protecting individual region sample data privacy and allowing multiple dataset integration across different regions. An independent ethical review group joined with a dashboard displaying real-time accuracy data will create an environment of transparency and trust among the users.

### C) Establishing a Formalin-Free Handling Ecosystem

Working with policymakers and the agricultural sector should be the highlight of the project since it will promote formalin-free handling alternatives instead of depending only on protective methods for handling formalin. Establishing a vendor and farmer certification program dedicated to formalin-free produce will drive commercial opportunities that lead to widespread ethical handling standards across the market. Workplaces should employ IoT-based safety sensors as these devices can both sense hazardous situations and launch protective reactions.

### D) Implementing Ethical Data Governance With Community Oversight

Sounds secure that the project should protect sensitive information through a blockchain-based record-keeping system for both security and traceability functions. Suppliers, along with farmers, should exercise encrypted data access control in order to allow authorized permission changes at their discretion. The implementation of scheduled ethical ML workshops helps stakeholders master data accountability principles and builds their capacity as technology provider accountability enforcers.

### E) Creating a Transparent Marketplace for Fair Agricultural Trade

An independent audit mechanism linked to a verification request system should terminate in the system to support fair trade among farmers. The development of a digital platform granting premium pricing to quality-verified apples promotes ethical grading practices by providing incentives to stakeholders. The prevention of price manipulation during classification requires a farmer cooperative system that conducts collective reviews before finalizing results to ensure transparent pricing practices.

## 9.4 Conclusion

Engineers need to conduct immediate morality evaluations on all projects that impact public health safety and market fairness. A high level of measurement accuracy must be maintained for formalin detection with the apple classification system to ensure consumer protection and reputational sustainability and to minimize biased model outputs. Being responsible in engineering practice through systems that handle errors smartly, along with learning technology and security measures across data management, allows organizations to build reliability and win public trust. Better transparency and ethical as well as sustainable business operations, emerge from the collaborative work between stakeholders and policymakers alongside regulatory bodies. Food safety improvements and equitable agricultural trade emerge from this project by using technology ethically alongside a mechanism that builds consumer confidence through sustainability-based food qualitative evaluations.

# Chapter 10: Conclusion and Future Work.

## 10.1 Project summary/Conclusion

The system designed has successfully achieved a dual-modality approach that detects adulteration in apples and assesses its quality through image processing techniques, making addressing critical food concerns and obtaining a comprehensive quality assessment convenient through a single platform.

We obtained high sensitivity and specificity with the help of sensor array implementation for formalin detection, while the image processing subsystem efficiently functioned in assessing the apple quality parameters with the help of a CNN algorithm. Integrating the technologies has enabled us to achieve rapid, non-destructive evaluations that possess the potential to enhance the food safety protocols and quality control mechanisms in the supply chain of fruits to a significant level.

The project contributes valuable methodologies for addressing widespread concerns regarding chemical adulteration in fresh produce while streamlining quality control processes. Our research and developed system prove that with the help of automated detection systems, we can provide the consumers with an accessible and scalable solution to help protect them from harmful food contaminants, simultaneously ensuring consistent product quality.

## 10.2 Future work

Several promising avenues for future research and development have been identified:

1. Miniaturization and Portability: Further development work on the main body of the project could help reduce its size, creating a handheld device that would be easier to carry and more suitable for field testing by farmers, market inspectors, and consumers.
2. Expanded Chemical Detection: By expanding the sensor array, it could be made adaptable to detect more adulterants found in fruits, such as calcium carbide, various pesticide residues, oxytocin, etc.
3. Enhanced Machine Learning Integration: By implementing more deep learning techniques, i.e., transfer learning, the classification accuracy could be improved for reduced computational requirements, potentially creating opportunities for real-time analysis on mobile devices.
4. Development of Mobile Application: By creating an application for smartphones that would interface with simplified sensors, users can be empowered to verify food safety and quality on their own.
5. Multi-fruit Adaptability: By extending the detection and classification abilities of the system to accommodate other fruits and vegetables that are commonly adulterated, the utility of the device can be increased.
6. Industrialization: By adapting the dataset and integrating better cameras into the system, the device can be used directly in warehouses that receive shipments of

apples. We can nip the problem at the bud by determining and cutting off suppliers that use dishonest means.

Following through with these future directions, the technology we created has the potential to evolve into a global solution for ensuring food safety and quality across global markets. This will help in lowering the public health risks associated with food adulteration and simultaneously improving the produce quality assessment technology.

# Chapter 11: Identification of Complex Engineering Problems and Activities.

## 11.1: Identify the attribute of complex engineering problem (EP)

**Table 14:** Attribute of complex engineering problem (EP)

| | **Attributes** | **Put tick (√) as appropriate** |
|---|---|---|
| P1 | Depth of knowledge required | √ |
| P2 | Range of conflicting requirements | |
| P3 | Depth of analysis required | √ |
| P4 | Familiarity of issues | √ |
| P5 | Extent of applicable codes | |
| P6 | Extent of stakeholder involvement and needs | √ |
| P7 | Interdependence | √ |

## 11.2: Provide reasoning how the project address selected attribute (EP)

P1. Depth of knowledge required:
The project requires knowledge of multiple fields which comes together in harmony to see the project to fruition.

- Knowledge of Embedded systems, IoT, ML, sensors
- Knowledge of Image Processing
- Knowledge of Design Process
- Knowledge of Tools required to develop the solution

P3. Depth of analysis required

- No single way to design the solution
- Depth of analysis is required to find the different alternative solutions and find the optimal/best solutions among alternatives.

P4. Familiarity of issues

- The project involves infrequently encountered issues.
- Agricultural and chemical issues are not usually taught in the EEE/ECE curriculum. Students need to learn these unfamiliar issues by themselves while designing the solution.

P6. Extent of stakeholder involvement and needs

- Consumers – Individuals purchasing apples who need assurance of quality and safety.
- Farmers & Orchard Owners – Producers who want to ensure that their apples meet market standards and remain free from harmful adulterants.
- Fruit Vendors & Retailers – Sellers who need to maintain high-quality stock and build consumer trust.
- Food Safety Authorities & Regulatory Bodies – Organizations responsible for enforcing food safety standards and ensuring compliance with regulations.
- Supermarkets & Food Chains – Large retailers who require reliable quality checks before selling apples to customers.

P7. Interdependence

Project involves a number of interdependent sub systems working together in symphony.

### 11.3 Identify the attribute of complex engineering activities (EA)

**Table 15:** Attribute of complex engineering activities (EA)

| | **Attributes** | **Put tick (√) as appropriate** |
|---|---|---|
| A1 | Range of resource | √ |
| A2 | Level of interaction | |
| A3 | Innovation | |
| A4 | Consequences for society and the environment | √ |
| A5 | Familiarity | √ |

### 11.4 Provide reasoning how the project address selected attribute (EA)

A1. Range of resource

Communication is required to mobilize various resources including money, people, equipment and information to implement the project.

A4. Consequences for society and the environment

Society will fare much better due to the reduced health and safety issues.

A5. Familiarity

This is an unfamiliar area for EEE/ECE students.

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## Appendix

**Related code/theory:**

```
import tensorflow as tf
 print("Available GPUs:", tf.config.list_physical_devices('GPU'))

import tensorflow as tf
 from tensorflow import keras
 from tensorflow.keras.preprocessing.image import ImageDataGenerator
 import numpy as np
 import os
 import shutil
 import random

# Define image size and batch size
 IMG_SIZE = (150, 150)
 BATCH_SIZE = 16
 EPOCHS = 100  # You can increase if needed

# Original dataset path (Change if needed)
 DATASET_PATH = "/kaggle/input/apple-data/Apple"


 # Temporary split folders
 TRAIN_PATH = "/kaggle/working/train/"
 VAL_PATH = "/kaggle/working/val/"

# Ensure directories exist
 for folder in [TRAIN_PATH, VAL_PATH]:
        for grade in ["A", "B", "C"]:
        os.makedirs(os.path.join(folder, grade), exist_ok=True)


 # Function to split dataset into train (80%) and validation (20%)
 def split_dataset():
```

```
        for grade in ["A", "B", "C"]:
        image_files = os.listdir(os.path.join(DATASET_PATH, grade))
        random.shuffle(image_files)

        split_idx = int(len(image_files) * 0.8)  # 80% Train, 20% Validation
        train_files = image_files[:split_idx]
        val_files = image_files[split_idx:]

        for file in train_files:
         shutil.copy(os.path.join(DATASET_PATH, grade, file), os.path.join(TRAIN_PATH,
grade, file))
        for file in val_files:
         shutil.copy(os.path.join(DATASET_PATH, grade, file), os.path.join(VAL_PATH,
grade, file))

 # Split the dataset
 split_dataset()

# Data Augmentation for training
 train_datagen = ImageDataGenerator(
        rescale=1./255,  # Normalize pixel values
        rotation_range=30,
        width_shift_range=0.2,
        height_shift_range=0.2,
        shear_range=0.2,
        zoom_range=0.2,
        horizontal_flip=True
 )

 val_datagen = ImageDataGenerator(rescale=1./255)  # Only rescaling for validation

 # Load dataset from newly created train and val directories
 train_data = train_datagen.flow_from_directory(
        TRAIN_PATH,
```

```
        target_size=IMG_SIZE,
        batch_size=BATCH_SIZE,
        class_mode='sparse'  # Sparse categorical (A=0, B=1, C=2)
 )

 val_data = val_datagen.flow_from_directory(
        VAL_PATH,
        target_size=IMG_SIZE,
        batch_size=BATCH_SIZE,
        class_mode='sparse'
 )

# Define CNN model
 model = keras.Sequential([
        keras.layers.Conv2D(32, (3,3), activation='relu', input_shape=(150,150,3)),
        keras.layers.MaxPooling2D(2,2),
        keras.layers.Conv2D(64, (3,3), activation='relu'),
        keras.layers.MaxPooling2D(2,2),
        keras.layers.Conv2D(128, (3,3), activation='relu'),
        keras.layers.MaxPooling2D(2,2),
        keras.layers.Flatten(),
        keras.layers.Dense(512, activation='relu'),
        keras.layers.Dense(3, activation='softmax')  # 3 output classes
 ])

# Compile model
 model.compile(optimizer='adam', loss='sparse_categorical_crossentropy',
metrics=['accuracy'])

# Train model
 model.fit(train_data, validation_data=val_data, epochs=EPOCHS)

# Save model
 model.save('/kaggle/working/apple_grade_model.h5')
```

```
# Convert to TensorFlow Lite for Raspberry Pi
 converter = tf.lite.TFLiteConverter.from_keras_model(model)
 tflite_model = converter.convert()
 with open('/kaggle/working/apple_grade_model.tflite', 'wb') as f:
           f.write(tflite_model)

 print("✅ Model training complete! Saved as 'apple_grade_model.h5' and
'apple_grade_model.tflite'")

import tensorflow as tf
 import numpy as np
 import os
 from tensorflow.keras.preprocessing.image import ImageDataGenerator
 from sklearn.metrics import classification_report, confusion_matrix

 # Load trained model
 model = tf.keras.models.load_model("/kaggle/working/apple_grade_model.h5")

 # Define validation directory path
 val_dir = "/kaggle/working/val"  # Update with your validation folder path

 # Create a data generator for validation set
 val_datagen = ImageDataGenerator(rescale=1./255)

 val_generator = val_datagen.flow_from_directory(
           val_dir,
           target_size=(150, 150),  # Must match training image size
           batch_size=32,
           class_mode='categorical',
           shuffle=False  # No shuffling to match labels
 )

 # Get ground truth labels
 true_labels = val_generator.classes
```

```
class_names = list(val_generator.class_indices.keys())  # Class names (A, B, C)

# Get model predictions
predictions = model.predict(val_generator)
predicted_labels = np.argmax(predictions, axis=1)  # Convert to class index

# Compute metrics
print("📊 Classification Report:")
print(classification_report(true_labels, predicted_labels, target_names=class_names))

# Compute confusion matrix
print("🌀 Confusion Matrix:")
print(confusion_matrix(true_labels, predicted_labels))
import matplotlib.pyplot as plt
from sklearn.metrics import confusion_matrix

# Replace with your actual labels
class_names = ['A', 'B', 'C']

# Compute the confusion matrix
cm = confusion_matrix(true_labels, predicted_labels)

# Plot manually using matplotlib
fig, ax = plt.subplots()
im = ax.imshow(cm, cmap='Blues')

# Show all ticks
ax.set_xticks(range(len(class_names)))
ax.set_yticks(range(len(class_names)))

# Label them
ax.set_xticklabels(class_names)
ax.set_yticklabels(class_names)
```

```
# Show labels
plt.xlabel('Predicted')
plt.ylabel('True')
plt.title('Confusion Matrix')

# Loop over data dimensions and create text annotations
for i in range(len(class_names)):
        for j in range(len(class_names)):
        ax.text(j, i, cm[i, j], ha='center', va='center', color='black')

plt.colorbar(im)
plt.show()



from sklearn.metrics import accuracy_score, precision_score, recall_score, f1_score

# Load the model
model = tf.keras.models.load_model('apple_grade_model.h5')

# Define validation directory
val_dir = '/kaggle/working/val/'  # Update with your actual validation directory path

# ImageDataGenerator setup for validation data
val_datagen = ImageDataGenerator(rescale=1./255)

val_generator = val_datagen.flow_from_directory(
        val_dir,
        target_size=(150, 150),  # Size must match the size you trained on
    batch_size=32,
        class_mode='categorical',
        shuffle=False  # Don't shuffle for metrics calculation
)
```

```
 # Get true labels
 true_labels = val_generator.classes

 # Make predictions on the validation set
 predictions = model.predict(val_generator)
 predicted_labels = np.argmax(predictions, axis=1)  # Convert predicted probabilities to class
labels

 # Calculate overall accuracy
 accuracy = accuracy_score(true_labels, predicted_labels)

 # Calculate overall precision, recall, and F1-score (macro average)
 precision = precision_score(true_labels, predicted_labels, average='macro')
 recall = recall_score(true_labels, predicted_labels, average='macro')
 f1 = f1_score(true_labels, predicted_labels, average='macro')

 # Display the results
 print(f"Overall Accuracy: {accuracy}")
 print(f"Overall Precision (macro): {precision}")
 print(f"Overall Recall (macro): {recall}")
 print(f"Overall F1-Score (macro): {f1}")
```

```
import numpy as np
 import tensorflow as tf
 from tensorflow.keras.preprocessing import image as keras_image  # Import image as
keras_image to avoid name conflict
 import matplotlib.pyplot as plt

 # Load your trained model
 model = tf.keras.models.load_model('apple_grade_model.h5')

 # Path to the image you want to test
 image_path = '/kaggle/input/apple-data/Apple/C/image_20250322_113126.png'  # Update
```

```
with the actual path to your image

 # Load the image and preprocess it
 img = keras_image.load_img(image_path, target_size=(150, 150))  # Resize the image to
match the input size
 img_array = keras_image.img_to_array(img)  # Convert the image to an array
 img_array = np.expand_dims(img_array, axis=0)  # Add a batch dimension

 # Normalize the image (assuming you used rescaling during training)
 img_array = img_array / 255.0  # Same normalization used during training

 # Predict the class
 predictions = model.predict(img_array)
 predicted_class = np.argmax(predictions, axis=1)  # Get the predicted class index

 # Get the class names (you can change these according to your dataset classes)
 class_names = ['A', 'B', 'C']  # Replace with your class names if different

 # Display the image and prediction result
 plt.imshow(img)
 plt.title(f"Predicted: {class_names[predicted_class[0]]}")
 plt.axis('off')  # Hide axes for better visualization
 plt.show()

 # Print prediction
 print(f"Predicted class: {class_names[predicted_class[0]]}")
 print(f"Confidence: {predictions[0][predicted_class[0]]}")
```

**Logbook:**

**Table 16:** FYDP (P) Summary of Team Log Book

| Date/Time /Place | Attendee | Summary of Meeting Minutes | Responsible | Comment by ATC |
|---|---|---|---|---|
| 10.06.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1.Need to finalize the title.<br>2.Need to finalize the problem statement.<br>3.Need to prepare a draft concept note | Task 1: Prithwi<br>Task 2: Isty<br>Task 3:Prithwi, Isty, Rafsun, Zarif | N/A as it was an introductory meeting.<br>Task 1: completed.<br>Task 2: not started.<br>Task 3: have not started yet. |
| 20.06.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1.Need to finalize the problem statement.<br>2.Need to prepare a draft concept note | Task 1: Prithwi and Isty<br>Task 3:Prithwi, Isty, Rafsun, Zarif | Task 1: Partially Completed<br>Task 2: Have not started yet. |
| 27.06.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1.Need to finalize the problem statement.<br>2.Need to prepare a draft concept note | Task 1: Prithwi and Isty<br>Task 3:Prithwi, Isty, Rafsun, Zarif | Need to revisit the problem statement in the coming week. Might even need to come up with a completely different problem to tackle<br>Task 1: Completed<br>Task 2: Completed |
| 02.07.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1. Prepare Presentation slides | Task 1: Prithwi, Isty, Rafsun, Zarif | Narrow down the topic even further if possible.<br>Task 1: In progress |
| 08.07.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4. Zarif | 1. Add more dimensions if possible<br>2. Do further research on the feasibility and datasets | Task 1: Prithwi, Rafsun<br>Task 2: Prithwi, Isty, Rafsun, Zarif | Find better papers to make the work easier<br>Task 1: In progress<br>Task 2: Completed |
| | | | | |
| 01.09.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun | Task 1: Literature review and gap for project proposal<br>Task 2: Methodology of approaches | Task 1: Prithwi<br>Task 2: Isty and Rafsun | Task 1: Completed<br>Task 2: Completed |
| 05.09.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Obtain permission to get formalin to carry out experiments to check sensors.<br>Task 2: Scope and objective | Task 1: Isty, Rafsun<br>Task 2: Prithwi | ATC's suggested interdepartmental communication to obtain formalin so we were instructed to draft and application<br>Task 1: In progress |

| | | | | |
|---|---|---|---|---|
| | | | | Task 2: Completed |
| 12.09.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Requirements, Specifications, and Constraints<br>Task 2: Block Diagrams<br>Task 3: Project Plan<br>Task 4: Ethical Considerations and identification of complex engineering attributes | Task 1: Isty<br>Task 2: Rafsun<br>Task 3: Zarif<br>Task 4: Prithwi | Task 1: Completed<br>Task 2: Completed<br>Task 3: Completed<br>Task 4: Completed |
| 19.09.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Safety Consideration<br>Task 2: Risk assessment<br>Task 3: Applicable standards and codes | Task 1.Prithwi<br>Task 2.Zarif<br>Task 3. Isty | Mock presentation was given and we were instructed to add more details. We were also instructed to combine the block diagrams for the two functions of our design.<br>Task 1: Completed<br>Task 2: Completed<br>Task 3: Completed |
| 26.09.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task: Finishing and polishing the report and making the slides based on feedback | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |

**Table 17:** FYDP (D) Summary of Team Log Book

| Date/Time /Place | Attendee | Summary of Meeting Minutes | Responsible | Comment by ATC |
|---|---|---|---|---|
| 22.10.24 | 1.Prithwi<br>2. Isty | 1. Need to talk to sir about how to proceed<br>2. Need to collect formalin by contacting pharmacy department to check sensor sensitivities | Task 1: Prithwi<br>Task 2: Isty | Was instructed to find a dataset that matches the number of classes we are aiming for. |
| 26.10.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | This was a small online meeting with Tasfin Sir who showed us a notebook we can use to start working on the image processing part of the project. | | We were instructed to keep running the notebook on our own time and prepare out dataset |
| 27.10.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1. Need to learn about image processing.<br>2. Hardware Simulation of the stepper motor<br>3. Hardware Simulation of sensors | Task 1: Prithwi<br>Task 2: Zarif and Isty<br>Task 3: Rafsun | |
| 31.10.24 | 1.Rafsun<br>2.Isty<br>3.Prithwi | A general meeting with the ATCs to get them up to date with our working | | |

| | | | | |
|---|---|---|---|---|
| 1.11.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | There were some places we got stuck in during our simulation so after a bit more self learning we got back to it.<br><br>1. Operational verification of approach 1<br>2. Simulation of Gas Sensors for approach 1<br>3. Finding Dataset | Task 1: Isty and Zarif<br>Task 2: Rafsun<br>Task 3: Prithwi | |
| 4.11.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | We got our hands on the camera module for design approach 1. Had a meeting with sir in order to fix certain issues we were facing with our raspberry pi. | | |
| 7.11.24 | 1.Prithwi<br>2. Rafsun | 1. Create the neural network architecture for our model.<br><br>2. Start reading articles on how to start the simulation for our Approach 2 | Task 1: Prithwi<br>Task 2: Rafsun | Verify the sensor block designed in approach 1 by cross checking with the graph obtained from it with the datasheet graph |
| 11.11.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Make the sensor block as per the instruction from sir.<br>Task 2: Start Approach 2 simulation for Spectroscopy | Task 1: Isty<br>Task 2: Rafsun and Prithwi | |
| 22.11.24 | 1.Isty<br>2.Rafsun<br>3. Prithwi | Task 1. Learn 3D design to formulate the body of the project.<br>Task 2: Start Approach 2 simulation for Colorimetry<br>Task 3: Go through the thousands of pictures in the dataset to arrange them accordingly | Task 1: Isty<br>Task 2: Rafsun<br>Task 3: Prithwi | |
| 30.11.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Start the writing of the report based on the work done so far Task 2: Start preparing the slides for progress presentation. | Task 1: Prithwi, Isty, and Rafsun<br><br>Task 2: Prithwi, Isty, Rafsun and Zarif | |
| 06.12.24 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: 3D designs for our approach 1<br>Task 2: Use CNN for model training. Task 3: Use Transformer for model training | Task 1: Isty<br>Task 2: Prithwi<br>Task 3: Rafsun and Zarif | Models could not be trained properly on our home workstations. It would stop after a few epochs. Need to get access to better GPUs for training. |
| 15.12.24 | 1.Prithwi<br>2.Isty | Task 1: Keep working on the report till we get access to better GPUs | Task 1: Prithwi, Isty, Rafsun and | |

| | | | | |
|---|---|---|---|---|
| | 3.Rafsun<br>4.Zarif | | Zarif | |
| 26.12.24 | 1. Prithwi | Task 1: Train the CNN models | Task 1: Prithwi | The performance metrics were less than satisfactory |
| 29.12.24 | 1. Prithwi | Task 1: Update and tweak the CNN model to try and get better results Task 2: Also side by side try a pretrained model such as EfficientNetB2 | Task 1: Prithwi<br>Task 2: Prithwi | The EfficientNetB2 model did worse, so it has been left out from consideration.<br>CNN performance metrics increased, however it was still pretty bad in accuracy for some of the grades. Might be due to dataset imbalance |
| 5.1.25 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Start hardware assembly so that dataset could be made ASAP.<br>Task 2: Update the slides and report for final presentation. | Task 1: Isty, Zarif and Rafsun.<br>Task 2: Prithwi | |
| 9.1.25 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Give final FYDP D presentation in front of all faculties present | | Focus on creating dataset on only one type of apple as otherwise the project load will be huge |
| 14.1.25 | 1. Prithwi | Report Submission | | |

**Table 18:** FYDP (C) Summary of Team Log Book

| Date/Time /Place | Attendee | Summary of Meeting Minutes | Responsible | Comment by ATC |
|---|---|---|---|---|
| 20.01.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1. Setup of controlled environment using 3D printed parts and components purchased online from tech shops<br>2. Come up with an architecture better suited for our now much smaller volume of dataset | Task 1: Isty,Rafsan,Zarif<br>Task 2: Prithwi | N/A as it was during the semester break<br>Task 1: Partially completed<br>Task 2: Completed. |
| 26.01.2025 | 1.Prithwi<br>2.Isty | 1. Check formalin sensor testing | Task 1: Prithwi, Isty | Task 1: Completed<br>Task 2: In progress. |

| | | | | |
|---|---|---|---|---|
| | 3.Rafsun<br>4.Zarif | 2. Need to prepare the platform, which will rotate at 45 45-degree interval | Task 2: Rafsun, Zarif | |
| 02.02.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1. Control the light inside the environment<br>2. Need to take 8 pictures using the web camera and save them in the pi's directory | Task 1: Isty, Zarif<br>Task 2:Prithwi, Rafsun | Lighting consistency and motor sync together before initializing the dataset creation<br>Task 1: Completed<br>Task 2: Completed |
| 06.02.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | 1. Troubleshoot Pi-related issues | Task 1: Isty, Rafsun, Zarif, Prithwi | Task 1: Completed |
| 08.02.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4. Zarif | 1. Purchase of 3 different batches of apples<br>2. Do further research on the CNN model to be used | Task 1: Zarif, Rafsun<br>Task 2:Prithwi, Isty | Task 1 Partially: Completed<br>Task 2: In progress |
| 10.02.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun | Task 1: Finalised the CNN model and local environment for Pi<br>Task 2: Dataset creation, initialization | Task 1: Isty, Rafsun<br>Task 2: Prithwi, Zarif | Task 1: Completed<br>Task 2: On progress |
| 25.02.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Obtaining a standardized dataset for Grade A apples in light controlled environment | Task 1: Isty, Rafsun | Task 1: Completed |
| 10.03.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Dataset for Grade B apples achieved in the light-controlled environment | Task 1: Zarif, Prithwi | Task 1: Completed |
| 25.03.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Successfully creating a dataset for Grade C apples in the light-controlled environment.<br>Task 2: CNN model training initialization | Task 1.Prithwi, Isty<br>Task 2: Prithwi, Zarif, Rafsun | Task 1: Completed<br>Task 2: In progress |
| 03.04.2024 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Validation and testing of the CNN model using various samples | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |
| 07.04.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Progress presentation task split | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |
| 10.04.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1:Attending progress presentation | Task: Prithwi, Isty, Rafsun and Zarif | |
| 17.04.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Forming a bridge between the formalin detection and quality sorting process. | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |
| 20.04.2025 | 1.Prithwi<br>2.Isty | Task 1: Preparing the final report writing draft. | Task: Prithwi, Isty, Rafsun and Zarif | Task: in progress |

| | | | | |
|---|---|---|---|---|
| | 3.Rafsun<br>4.Zarif | | | |
| 27.04.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Final report draft completed. | Task: Prithwi, Isty | formatting, alignment, sentence structures, Adding loss graphs, etc |
| 01.05.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Preparation of poster. | Task: Rafsun, Zarif | Adding infographics, more bullet points, QR code.etc |
| 08.05.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: Revision of the updated final report and poster | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |
| 13.05.2025 | 1.Prithwi<br>2.Isty<br>3.Rafsun<br>4.Zarif | Task 1: final prototype testing before demonstration day | Task: Prithwi, Isty, Rafsun and Zarif | Task: Completed |

## Assessment Guideline for Faculty

[The following assessment guideline is for faculty ONLY. **This portion is not applicable for students**.]

### Assessment Tools and CO Assessment Guideline

| | **Distribution of assessment points among various COs assessed in different semesters** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PO | l | c | f | g | c | b | d | c | e | l | k | k | h | i | j |
| CO | CO 1 | CO 2 | CO 3 | CO 4 | CO 5 | CO 6 | CO 7 | CO 8 | CO 9 | CO 10 | CO 11 | CO 12 | CO 13 | CO 14 | CO 15 |
| EEE 400C/ ECE 402C<br>(Out of 100) | | | | | | | 30 | 24 | 6 | 4 | 4 | 6 | 7 | 7 | 12 |
| Project Final Report/ Project Progress Report | | | | | | | x | x | x | x | x | x | x | | x |
| Demonstration of working prototype | | | | | | | x | | | | | | | | x |
| Progress Presentation/ Final Presentation | | | | | | | | x | | | x | | | | |
| Peer-evaluation* | | | | | | | | | | | | | x | x | |
| Instructor's Assessment* | | | | | | | | | | | | | x | x | |
| Demonstration at FYDP Showcase | | | | | | | | x | | | | | | | x |

Note: The star (*) marked deliverables/skills will be evaluated at various stages of the project.

**Mapping of CO-PO-Taxonomy Domain & Level- Delivery-Assessment Tool**

| Sl. | CO Description | PO | Bloom's Taxonomy Domain/Level | Assessment Tools |
|---|---|---|---|---|
| CO7 | **Evaluate** the performance of the developed solution with respect to the given specifications, requirements and standards | d | Cognitive/ Evaluate | ● Demonstration of working prototype<br>● Project Progress Report on working prototype |
| CO8 | **Complete** the final design and development of the solution with necessary adjustment based on performance evaluation | c | Cognitive/ Create | ● Project Final Report<br>● Final Presentation<br>● Demonstration at FYDP Showcase |
| CO9 | **Use** modern engineering and IT tools to design, develop and validate the solution | e | Cognitive/ Understand, Psychomotor/ Precision | ● Project Final Report |
| CO10 | **Conduct** independent research, literature survey and learning of new technologies and concepts as appropriate to design, develop and validate the solution | l | Cognitive/ Apply | ● Project Final Report |
| CO11** | **Demonstrate** project management skill in various stages of developing the solution of engineering design project | k | Cognitive/ Apply<br>Affective/ Valuing | ● Project Final Report<br>● Project Progress presentation at various stages |
| CO12 | **Perform** cost-benefit and economic analysis of the solution | k | Cognitive/ Apply | ● Project Final Report |
| CO13 | **Apply** ethical considerations and professional responsibilities in designing the solution and | h | Cognitive/ Apply<br>Affective/ Valuing | ● Peer-evaluation, |

| | | | | |
|---|---|---|---|---|
| | throughout the project development phases | | | - Instructor's Assessment<br>- Final Report |
| CO14** | **Perform** effectively as an individual and as a team member for successfully completion of the project | i | Affective/ Characterization | - Peer-evaluation<br>- Instructor's Assessment |
| CO15** | **Communicate** effectively through writings, journals, technical reports, deliverables, presentations and verbal communication as appropriate at various stages of project development | j | Cognitive/ Understand<br>Psychomotor/ Precision<br>Affective/ Valuing | - Project Final Report<br>- Progress Presentations,<br>- Final Presentation<br>- Demonstration at FYDP Showcase |

Note: The double star (**) marked CO will be assessed at various stages of the project through indirect deliverables.